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**The neural substrates of the self-prioritisation effect:
the role of familiarity and emotionality**

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Abbreviations

CLARA – Classical LORETA Recursively Applied

EEG – electroencephalography

ERP – event-related potential

fMRI – functional magnetic resonance imaging

FRU - face recognition unit

IPA – implicit positive association

LPP – late positive potential

PIN - person identity node

SAN – self attentional network

SPE – self-prioritisation effect

SIU - semantic information unit

Streszczenie

Ilość informacji napływających z otaczającego świata jest ogromna i przytłaczająca. Niemniej jednak, ludzie nie doświadczają stale konsekwencji ich ogromnego napływu. Jest to przede wszystkim wynik zachodzenia selekcji informacji, która nie zawsze jest zależna od świadomych decyzji. Jednym z możliwych kryteriów w selekcjonowaniu informacji jest odniesienie jej do własnej osoby i wydajniejsze jej przetwarzanie. Efekt ten nazywany jest efektem priorytetyzacji informacji związanych z JA (ang. *self-prioritisation effect*, SPE). Chociaż SPE obserwuje się w wielu różnych kontekstach, czynniki odpowiedzialne za to zjawisko są wciąż dyskutowane. W dotychczasowej literaturze postulowane były dwa czynniki, znaność/znajomość (ang. *familiarity*) i emocjonalność (ang. *emotionality*), lecz większość badań skupiała się głównie na pierwszym z nich. W pracy doktorskiej, wykorzystując metody elektrofizjologiczne, zamierzałam niezależnie zbadać rolę każdego z tych dwóch czynników.

Pierwsze dwa badania poświęcone były czynnikowi emocjonalności. Ponieważ emocje mogą być postrzegane obiektywnie lub subiektywnie, rozróżnienie to przeniosłam na badany przeze mnie czynnik emocjonalności. W pierwszym doświadczeniu skupiłam się na wpływie obiektywnej emocjonalności, porównując przetwarzanie własnej twarzy i nieznanymi twarzami emocjonalnymi. Analiza potencjałów wywołanych (skupiona na P3 i LPP) oraz testy permutacyjne oparte na klastrach aktywności mózgowej wykazały, że przetwarzanie twarzy własnej jest unikatowe i nie przypomina przetwarzania obiektywnie emocjonalnych twarzy. W kolejnym badaniu w centrum uwagi znalazła się subiektywna emocjonalność. Aby ocenić jej wpływ na SPE, do badania dodano twarz bliskiej osoby. Taka osoba prezentuje podobną kombinację czynników znaności i emocjonalności, jaką posiada JA, dlatego twarz bliskiej osoby wydaje się najlepszym porównaniem do własnej twarzy. Co więcej, ponieważ pandemia COVID-19 znacząco wpłynęła na życie ludzi w ciągu ostatnich kilku lat, cele tego badania zostały rozszerzone i przetestowano, czy SPE wystąpi również w przypadku, gdy jest niepełny dostęp do informacji o twarzach. Analiza źródeł pokazała, że przetwarzanie twarzy częściowo zakrytych angażuje typowy dla przetwarzania twarzy region mózgu, zakręt wrzecionowaty. Amplitudy wczesnych (P1) i późnych (P3, LPP) komponentów ERP spójnie wskazywały, że wszystkie zakryte twarze wymagały do przetworzenia większej uwagi, a maski chirurgiczne nie osłabiły SPE, gdyż twarz własna w obu warunkach (tzn. twarze z maseczkami lub bez) wywołała znacznie wyższe amplitudy P3 i LPP. Ponadto wystąpiła

istotna różnica pomiędzy przetwarzaniem twarzy własnej i twarzy bliskiej osoby. Ten układ wyników podważa potencjalną rolę subiektywnej emocjonalności, a w połączeniu z ustaleniami z pierwszego badania, ogólnie minimalizuje rolę emocjonalności.

Ostatnie badanie poświęcone było czynnikowi znaności. Aby rozdzielić wzajemne oddziaływanie obu badanych czynników, wyrównano poziom znaności prezentowanych bodźców. Oprócz wysoce znanych bodźców, jakimi są twarz własna i osoby bliskiej, wykorzystalam nieznane, abstrakcyjne kształty, które zostały arbitralnie przypisane uczestnikowi oraz osobie bliskiej (dowolnie przez niego wybranej). Analiza zgromadzonych danych nie wykazała różnic w przetwarzaniu nowo nabytej informacji pomiędzy warunkami JA i osoba bliska (amplitudy P3 i LPP nie różniły się istotnie). Ponieważ wzorzec wyników dla przetwarzania twarzy okazał się typowy (większe amplitudy P3 i LPP w warunku JA), brak różnic w przetwarzaniu pomiędzy kształtem przypisanym do JA a kształtem przypisanym bliskiej osobie może być interpretowany jako kolejny istotny argument na rzecz znaności jako czynnika warunkującego wystąpienie SPE.

Wyniki przedstawione w tej rozprawie wskazują, że znaność jest kluczowym czynnikiem w występowaniu zjawiska priorytetyzacji informacji związanych z JA. Wykorzystując różne paradygmaty i różnorodne techniki analiz wykazałam, że wysoka znaność informacji dotyczących JA jest kluczowa dla SPE. Badając wzajemne oddziaływanie między znanością a emocjonalnością, moja praca przyczynia się do głębszego zrozumienia, w jaki sposób ludzie przetwarzają informacje i podejmują decyzje w oparciu o SPE.

Abstract

The volume of information flowing in from the world is enormous and, in fact, overwhelming. Yet, individuals may not be constantly aware of this, as they do not permanently experience the consequences of this immense influx of information. This is primarily attributed to the selection process, which is not always contingent on conscious choices. One possible criterion for the selection of information is its association with the self, leading to more efficient processing. This effect is called the self-prioritisation effect (SPE). Although SPE is observed in many different contexts, the factors driving this phenomenon are still ambiguous. Scientists propound two factors, familiarity and emotionality, focusing mainly on the former. In this thesis, using electrophysiological techniques, I aimed to investigate the role of these two factors independently.

The first two studies were devoted to the emotionality factor. As emotions might be perceived objectively or subjectively, this distinction was transferred to the emotionality factor. In the first study, a plausible role of objective emotionality was investigated by comparing the processing of one's own face and emotional unknown faces. ERPs analysis (with P3 and LPP in the focus of attention) and cluster-based permutation tests revealed that the processing of the self-face is unique and does not resemble the processing of the objectively emotional faces. In the follow-up study, subjective emotionality was in the spotlight. To assess its impact on the SPE, a face of a close person was introduced into the study. Such a person presents a similar combination of familiarity and emotionality factors as is possessed by the self; thus, the face of a close-other seems to be the best comparison to the self-face. Moreover, as the COVID-19 pandemic significantly impacted human lives in the last few years, the study's goals were expanded, and the SPE was tested for partial facial information. Source analysis indicated that the processing of partially covered faces is associated with the brain area typically linked to the face processing, fusiform gyrus. Amplitudes of early (P1) and late (P3, LPP) ERP components consistently indicated that all covered faces require more attentional resources to be processed, and SPE is not impoverished by the surgical-like masks, as the self-face in both conditions (with and without mask) evoked significantly higher P3 and LPP amplitudes. Furthermore, a significant difference between the processing of the self-face and the close-other's face was depicted. This pattern of results undermines the plausible role of subjective emotionality, and in combination with findings from the first study, it deflates the role of emotionality in general.

The last study was dedicated to the familiarity factor. The familiarity of the presented stimuli was equalised to disentangle the mutual impact of both factors. Apart from the highly familiar stimuli as one's own and close-other's faces, we used unknown abstract shapes assigned to the participant and freely chosen close-other. Our findings revealed no differences in the processing of newly acquired information (as evidenced by similar P3 and LPP amplitudes in both cases). As the typical pattern of face processing was manifested (larger P3 and LPP for the self-face), the lack of differences between the self-assigned shape and the shape assigned to the close-other might be interpreted as a further substantial argument in favour of familiarity as a driving factor of self-prioritisation.

The findings presented in this thesis indicate that familiarity is a driving factor in the self-prioritisation effect. Through various paradigms and diverse analytical techniques, we have demonstrated that high familiarity of self-related information is crucial for the self-prioritisation effect. By shedding light on the intricate interplay between familiarity and emotionality, my work contributes to a deeper understanding of how individuals process information and make decisions based on SPE.

1. Introduction

The self is a colourful concept (Hommel, 2019). It captivates the interest of many different fields and becomes the backbone of multiple disputes. Descartes put 'self' in the role of agent in his hunt of proving human existence, corporate lobbies treat it as a target to win over, and personal development and coaching as a forever unattainable developmental goal in life (Hommel, 2019). However, despite the presence in so many different areas, it seems to be still an inscrutable concept. Ergo - what is the self?

Multiple researchers from diverse fields, like philosophy, psychology, psychiatry and neurobiology, have endeavoured to define 'self'. Neisser (1995) postulates a multifaceted perspective, suggesting that each individual possesses five different kinds of self-knowledge which are broadened during a lifetime: (1) the ecological self, (2) the interpersonal self, (3) the temporally extended self, (4) the private self, and (5) the conceptual self. According to that perspective, the self is not a fixed, rigid part of a person or mind but rather a whole person considered in the context in which the individual is situated. This spin of the self redirects attention from an inward-looking view based on private experience to an outward-looking view of the self within ecological and social contexts (Neisser, 1993).

Dennett (1991) offers an alternative approach, linking the concept of the self to language and describing it as the core of 'narrative gravity'. From this perspective, humans direct perception and construction of the world from the position of self-narration. Dennett's idea of the self as the centre of narrative gravity parallels a centre of gravity in the physical sense – a simplified, single point of origin (Dennett, 1991).

Sprung from Dennett's perspective, Gallagher (2000) introduced the concept of 'the minimal self' and 'the narrative self'. 'The minimal self' pertains to the self as perceived in the present moment, devoid of connections to other points on one's life timeline. In contrast, 'the narrative self' complements 'the minimal self' by encompassing the individual's identity and continuity across time.

Yet another perspective on the self emerges from Jeannerod (2003), who emphasises the role of recognising oneself as the owner and the agent of one's own body. This recognition stems from congruent proprioceptive and exteroceptive feedback. Jeannerod contends that the self of agency enables the establishment of a stable identity that remains independent from the external world.

A differentiation proposed by Gillihan and Farah (2005), in turn, pertains to the distinction between the physical and psychological dimensions of self. The physical aspects are typically investigated in studies focusing on self-face recognition, agency, and perspective-taking, while the psychological facets are usually measured through studies examining autobiographical memory and self-knowledge in terms of personality traits. This conceptual separation is supported by neuroimaging research, which indicates that processes related to the physical or embodied self and those linked to the psychological or evaluative self rely on distinct large-scale brain networks (Lieberman, 2007; Uddin et al., 2007).

Although presented definitions show different approaches to the self, they view it as a flexible, developing, and changing construct without sharp boundaries. These diverse perspectives on the self paint a nuanced picture, demonstrating this fundamental concept's complexity and multifaceted nature in human psychology.

The significance of the self in human life is profound. A fundamental feature of human experience is a sense of one's self as a unique unit, distinctive from others (James 1959/1890). The self encompasses a singular sense of identity, autobiographical memories of the past, and expectations and beliefs about the future (Macrae et al., 2004). Thus, disturbance of self is viewed as a core of some mental or personality disorders. Schizophrenia is translated as 'splitting of the mind' from Ancient Greek words (*σχίζειν*, *schizein*, 'to split' and *φρήν*, *phrēn*, 'mind'). Despite this name being misinterpreted, it captures the essence of this mental disorder. A person with schizophrenia is often unsure of being the owner of one's own thoughts (Scharfetter, 2003; Fletcher and Frith, 2009) or the agent of one's own actions (Scharfetter, 2003). Moreover, individuals with schizophrenia experience adversity in recognising their own face (Kircher and David, 2003; Zhou et al., 2020), parts of their body (Ferri et al., 2012), their own reflection in the mirror (Parnas, 2003; Szczotka and Majchrowicz, 2018) and differentiating it from themselves, i.e. indicating where a real person and reflection are (Blanke and Metzinger, 2009). Rubber hand illusion research showed that individuals with schizophrenia adapt faster than healthy controls (Thakkar et al., 2011), and their EEG signal remains unchanged before and during the experiment (Peled et al., 2003).

Difficulties in self perception are also observed in anorexia nervosa. Studies demonstrated that people with anorexia nervosa encounter obstacles in the proper evaluation of face

expression - they more often confound neutral self-face as sad than healthy controls (Phillipou et al., 2015).

Other mental disturbances affecting the representation of the self are presented in Internet gaming addiction. Leménager and colleagues (2016) showed that pathological Internet gamers generally demonstrates higher self-concept deficits. Moreover, analysis of fMRI data revealed hyperactivation of the left angular gyrus during avatar reflection, a region linked to identification processing and feeling of empathy. This hyperactivation was correlated with symptom severity (Leménager et al., 2016). Therefore, stable self-representation is a core of mental health.

Moreover, the self is crucial in our everyday cognitive functioning. We live in a world where we obtain more information than we need and more than we can process. Therefore, we must sieve through a wealth of information to pinpoint the crucial. The self may constitute ‘an information filter’ as a key to select incoming input for further processing. An excellent and universal example is the cocktail party effect (Moray, 1959), which shows that people can pick up one’s own name in the meaningless noise. This facilitation is not confined to names (Tacikowski and Nowicka, 2010; Tacikowski et al., 2013), as it exerts its influence on faces (Tacikowski and Nowicka, 2010; Tong and Nakayama, 1999; Keenan et al., 1999), other parts of the body (Ferri et al., 2012), self-reflection (Moran et al., 2006), and even handwriting (Chen et al., 2008). This phenomenon is known as a self-preference or self-prioritisation effect (SPE). Multiple research shows that due to the reference with the self, such information is more quickly and accurately detected, easier remembered (Magno and Allan, 2007; Nowicka et al., 2018) and recalled (Rogers et al., 1977). However, cognitive and social neuroscience ventures beyond behavioural studies, seeking to bolster the SPE with physiological techniques and find its neural substrates. Functional magnetic resonance imaging (fMRI) studies demonstrates the self-face increases activity of the medial prefrontal cortex, anterior cingulate cortex, and posterior cingulate cortex in comparison to other faces (e.g. Macrae et al., 2004; Philippi et al. 2012; Tacikowski et al., 2013). Moreover, Yankouskaya and Sui (2022) discovered that the interaction between the default mode network, frontoparietal network, and insular salience network is crucial for SPE occurring (Yankouskaya and Sui, 2022). A noteworthy contribution was also made by Tacikowski and colleagues (2013), who demonstrated that SPE appears for self-name presented visually and auditorily. SPE is related with increased activity in the medial

prefrontal cortex for both modalities and bilateral inferior frontal gyri for auditorily presented stimuli (Tacikowski et al., 2013).

As fMRI studies indicate critical brain regions for self-awareness and processing of information related to the self, electroencephalography (EEG) is more suitable for following temporal dynamics of brain responses to these stimuli. EEG research indicates a few components important for SPE. P3 (or P300) potential is reported in most studies concerning the processing of self-related stimuli. Multitude studies demonstrates significantly amplified P3 amplitude for one's own name or face than for names or faces related to other people, respectively (Perrin et al., 2005; Zhao et al., 2009; Tacikowski and Nowicka, 2010; Tacikowski et al., 2011; Fan et al., 2013; Cygan et al., 2014; Tacikowski et al., 2014). Moreover, such an increase of P3 amplitude is also observed for other self-related information like hometown, school, etc. (Gray et al., 2004). Similarly, research reports the enhancement of the P2 (or P200) potential, comparing self-name with other names (Fan et al., 2013) or autobiographical and nonsignificant information (Hu et al., 2011). Analogous findings are obtained for the comparison of personality trait words describing an individual and other-relevant people (Mu and Han, 2010; Liu et al., 2013).

Summing up, studies show that self-related information not only leads to stronger brain responses when compared to information linked to unknown people but also to celebrities, family members, and friends (Kotowska and Nowicka, 2016; Kotowska et al., 2023; Zhou et al., 2020).

There is considerably less agreement, however, about the nature of self-prioritisation. In this thesis, I will focus on the two most possible factors that may drive this phenomenon.

2. Description of the project: the general aim

A vast body of research has been dedicated to investigating the self-prioritisation effect, showing its substantial and widespread impact on everyday life (e.g. Moray, 1959). However, even though research indicates two major factors driving this phenomenon, it appears they have been not equally often investigated. The majority of studies has focused on the familiarity factor (e.g. Kotlewska and Nowicka, 2016), while the contribution of emotionality to the SPE is heretofore narrowly examined (e.g. Sui et al., 2012). This unequal interest has resulted in misrepresentation and an illusive understanding of this process. Therefore, one of the aims of this project was to suss and assess separately the role of these factors.

In order to answer the question mentioned above, a series of ERP experiments was conducted with experimental conditions differing mainly in respect to their emotional loads or familiarity levels.

Emotionality is not a one-dimensional concept. Definitions of emotion emphasise the individual and intrinsic perspective of every being (e.g. Frijda, 1986; Dolan, 2002), resulting in a subjective perception of every event in the world. Rainy day may be objectively assessed as heart-sickening while simultaneously recapturing pleasant memories in some people. Similarly, a smiling or fearful unknown face may be objectively perceived as emotional but not necessarily subjectively so. Therefore, to fully assess the role and possible impact of emotionality, it is crucial to consider not only objectively explicit emotional stimuli (e.g., happy faces) but also personally relevant ones (e.g., a partner's face). This issue might be addressed by introducing a freely chosen close-other person who presents a mixture of high familiarity and high subjective emotionality, as is the case for the self. This would reveal whether emotionality partakes in SPE and, if so, whether its character is objective or subjective.

Moreover, COVID-19 had an essential and unexpected input on this project. One of the crucial changes that the pandemic brought about was using surgical-like protective masks to cover our noses and mouths. This introduced a series of questions concerning processing human faces when they are partially concealed. Due to these new conditions, the project's scope was expanded to address additional questions - how faces (self, close-other, unknown) with masks are processed and whether the SPE would remain for covered self-face.

However, the self-face differs from the close-other's, emotional and neutral unknown faces not only in emotionality dimensions but also on familiarity level. Even though the majority of the studies is devoted to familiarity, they do not analyse it solely, as a face or a name makes up a combination of both aforementioned factors. Therefore, the third study aimed to investigate the familiarity in separation from emotionality. It was achieved by making presented stimuli equally familiar.

3. Description of research: background and results

3.1. Emotionality

3.1.1. Objective Emotionality

As it was aforementioned, emotionality is a complex and multilayered factor. The moment of our emotional development starts on the day of our birth or in the early months of life as the neural substrates become functional for some basic-emotion expressions (e.g. joy) (Izard et al., 1995), while for others within the first two years (Camras et al., 2002). Emotions are the significant information carrier and the impairment of their perception, understanding, and expression may lead to socialisation problems as it may be viewed in autism spectrum disorder (e.g. Kinnaird et al., 2019; Gaigg et al., 2018; Samson et al., 2015), patients with cerebellum tumour (e.g. Hoche et al., 2016; Beuriat et al., 2022; Schmahmann, 2010; Sokolov, 2018), or juvenile offenders (e.g. Hubble et al., 2015; Pincham et al., 2015; Shelton, 2001). Moreover, deficits in self-conscious emotions (a specific type of emotions developing when one encounters to identity-relevant events) may also lead to a diversity of psychopathological outcomes (Muris and Meesters, 2014).

Emotions may be defined as a distinctive, episodic outcome of evaluating an event through personal goals that modifies action readiness (Frijda, 1986). In other words, positive emotions may be evoked if an event furthers the personal objectives or negative if an event is perceived as an impediment. However, the role and function of emotion in life have sparked off a debate among the social scientists. Hard-line opinions propound emotions' uselessness, minimising their impact and even suggesting they negatively affect everyday functioning (e.g. Skinner, 1948; Mandler, 1984). Nevertheless, most scientists indicate that emotions play a part in the prioritisation and organisation of behaviour to enhance an individual's adjustment to the environment's physical and social demands (Ekman, 1992; Lazarus, 1991). The functional aspect of emotions might be best seen through 'basic emotions' such as happiness, fear, and anger. They are distinctive, acquired in the early period of life, and seem to appear to serve specific purposes (Izard, 2007). For instance, happiness is evoked in response to pleasant events, encouraging to repeat them in the future. In contrast, fear is generated when a person perceives an event as a threat or danger, leading to an F3 response (freeze, fight, or flight).

The first study, presented in this thesis, aimed to explore the objective emotionality in self-prioritisation. ERP responses to self-face were compared to objective emotional faces

as they may capture, hold and bias attention and avoid involving awareness, similarly to the self-face (Wójcik et al., 2019; Zotto and Pegna, 2015). As they activate the same areas in the brain, they might be expected to be processed similarly. Therefore, based on the self-positivity bias (Greenwald, 1980; Watson et al., 2007) and the theory of implicit positive association (IPA) with the self (Ma and Han, 2010), one may presume that self-face might be processed as an emotionally positive face (e.g. smiling face), as both can evoke positive feelings. Another crucial aspect of the self is saliency, a mutual feature with the fearful face. A neutral face was added as a control stimulus. It is also noteworthy that self-face differed from other faces in the aspect of familiarity. None of the non-self-face was known to the participants before the study. Participants were tasked with the simple detection of presented faces - they were asked to push the response button (same for each presented stimulus) as quickly as possible.

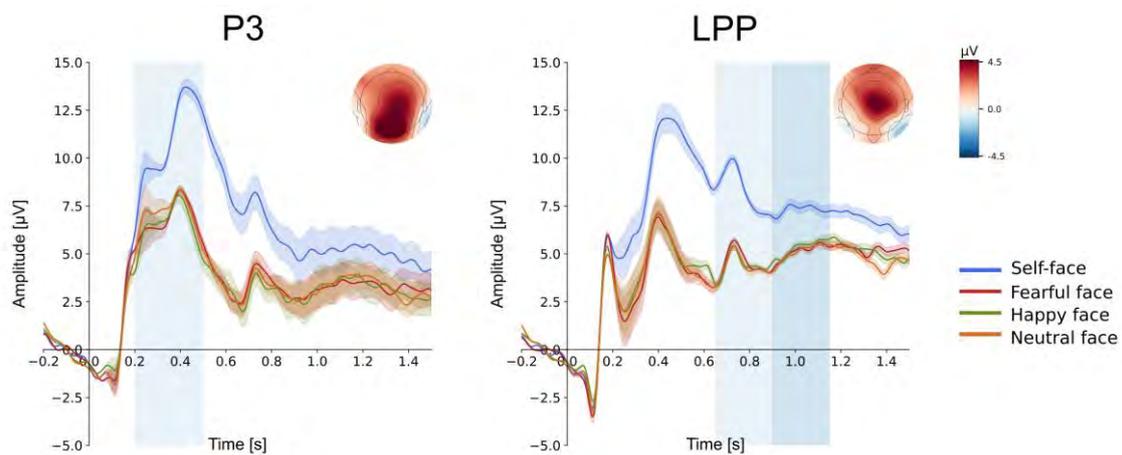


Figure 1. Grand average ERPs for self-face, fearful, happy, and neutral faces are presented. Shaded areas denote standard deviations (*SD*). In the left panel, the P3 component is shown, which is the average of pooled electrodes PZ, CPZ, CP2, and P2, located within the region of maximal activity in the topographical distribution of brain activity. This average is across all experimental conditions, encompassing four types of faces. The right panel displays the LPP, which is the average of pooled electrodes FCZ, FC2, and C2, also within the region of maximal activity in the topographical distribution of brain activity, averaged across all experimental conditions. The analysed time windows are highlighted with light-blue rectangles.

Comparison of the self-face with happy and fearful faces showed that the self-face is processed dissimilar to all other faces. ERP results showed a preference for the processing of one's own face. P3 and LPP components were significantly increased in comparison to emotional and neutral faces (mean amplitudes to the self-face were approximately two

times higher, Figure 1). Moreover, cluster-based permutation tests were deployed to this data. This method facilitates unbiased comparisons of EEG signals recorded under various experimental conditions across all sensors and time points. It achieves this by controlling for multiple comparisons and maximising statistical power, utilising the data's cluster structure as its sole test statistic. I applied this approach to assess differences in spatial and temporal distributions among the experimental conditions. Cluster permutation tests demonstrated that self-face processing differs from each emotional (happy or fearful) face (Figure 2).

Together, these results suggest that the driving factor of self-prioritisation is familiarity, as no resemblance was found between the self-face and any of the emotional faces.

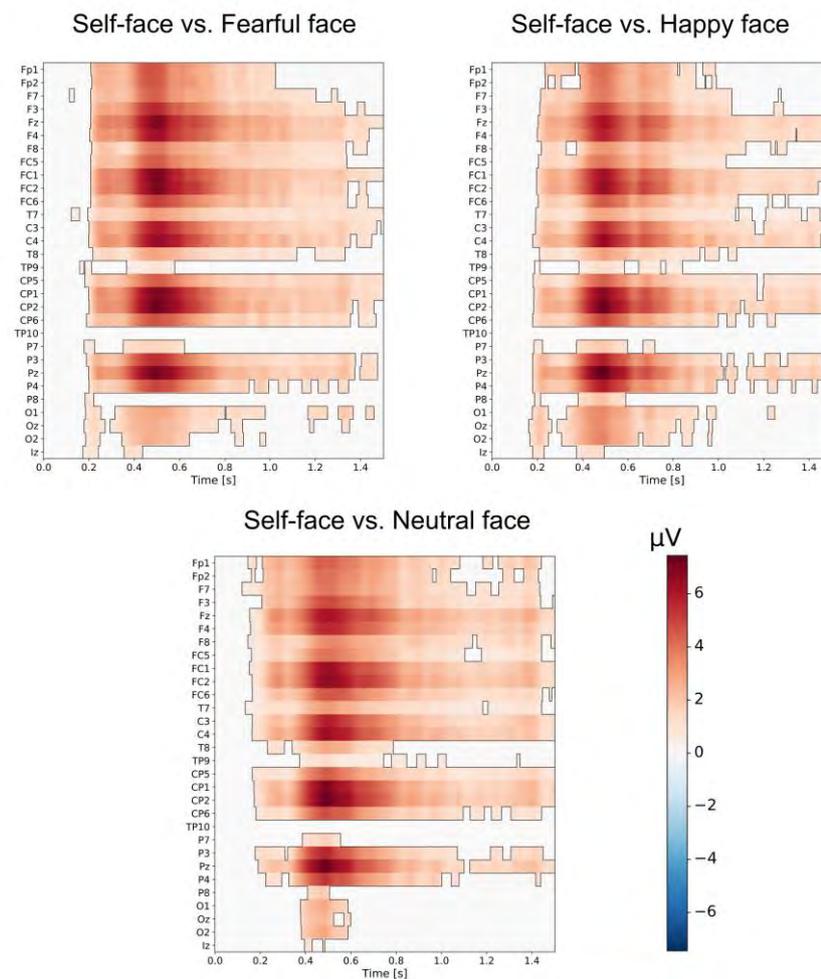


Figure 2. The results of cluster-based permutation tests are presented. Self-face was compared to fearful and happy faces in the top-left and top-right panels, respectively. Additionally, the self-face was compared to the neutral face in the bottom panel. Statistically significant positive differences between the tested experimental conditions are highlighted in red ($p < .05$). For clarity, only 30 electrodes from the total set of 62 are displayed for illustrative purposes.

3.1.2. *Subjective Emotionality*

A quite obvious feature of emotion is its subjectiveness. Whoever defines emotion discerns its intrinsic character (e.g. Frijda, 1986; Dolan, 2002), highlighting the unique and deeply personal nature of emotional responses. This subjectivity in emotional responses reflects the complex diversity of human psychology, influenced by personal history, cultural background, upbringing, and a multitude of other factors. It underscores the idea that emotions are deeply personal, and the emotional evaluation of one person may differ significantly from that of another in response to identical external stimuli or events (Dolan, 2002). Thus, people attach diverse emotional values to things, places, events, and, most notably - to people. For instance, seeing a joyful unknown person with flowers on a train station platform or a crying unknown child with an injured knee on the playground may arouse tenderness for the first and compassion for the latter. However, these emotions are diminished (or even swept off) if we notice our beloved on the platform or our child is injured. Therefore, an objectively emotional stimulus or event may lose its emotional valence if co-presented with a subjectively emotional stimulus or event. This indicates that traversing emotionality through the perspective of objective emotions sheds light only on the part of emotionality as a factor of self-prioritisation.

This shaded part might be investigated by adding a stimulus related to a close-other person who combines familiarity and emotionality on a comparable level to the self. This could help unveil if the distinctions between one's own face and objectively emotional faces are unique to the self or if other highly familiar and subjectively emotional faces undergo similar processing as the self. Consequently, this notion could enrich the ongoing discourse regarding whether the self is a higher-order or fundamental function of the brain.

The second study, presented in this thesis, aimed to determine the plausible role of subjective emotionality in self-prioritisation. As in the previous study, participants were tasked with a simple detection task. However, the current research used self-face, a close-other's person face, and a neutral face (as a control stimulus). Because of the COVID-19 pandemic, I decided to make research more ecologically valid by adding a surgical-like mask condition (Figure 3). Therefore, each face was presented with and without a mask which enabled me to answer additional questions: (1) how the human brain processes partially covered faces and (2) whether SPE appears for self-face hidden behind the surgical-like mask.



Figure 3. Here are examples of faces, with and without surgical-like masks, featuring two study co-authors.

The main concern of this study was the potential role of subjective emotionality. Analysis of P3 and LPP amplitudes unveiled that they were significantly enlarged for the self-face in comparison to other faces, including the close-other's face (Figure 5). Nevertheless, P3 amplitude also increased substantially more to the close-other's face than to the unknown. Furthermore, SPE for the self-face persisted, irrespective of the surgical-like mask's presence. Analysis of P1, P3, and LPP amplitudes revealed a general enhancement for faces covered with masks (Figure 4 and Figure 5). In addition, source analysis revealed that for both types of faces, brain activity was located in fusiform gyri (Figure 6).

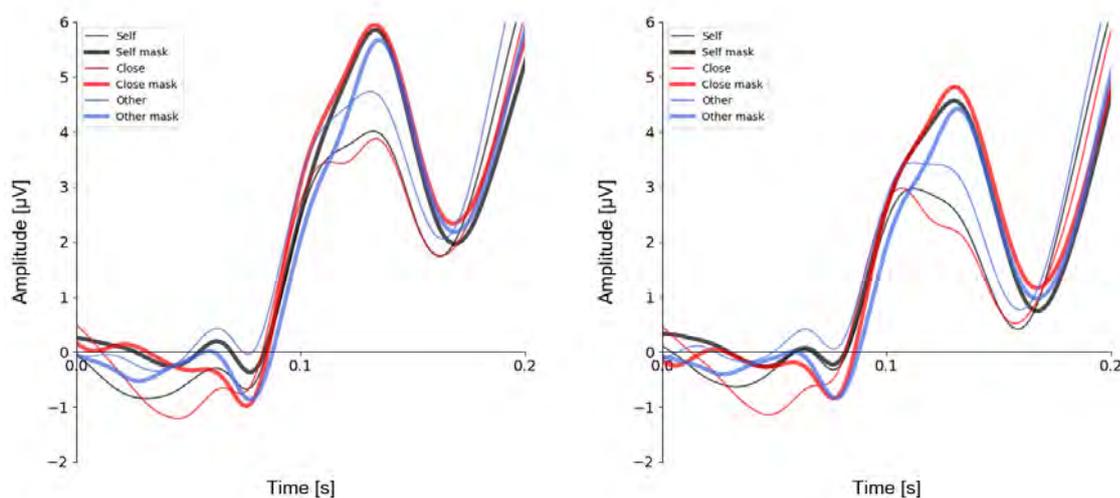


Figure 4. Here is the grand average of P1 ERP for self-face, close-other's face, and unknown face, both with and without a surgical-like mask. The P1 potential is computed from the combined data of electrodes O2 and PO4 in the right occipital-parietal region (right panel) and corresponding electrodes in the left occipital-parietal region, O1 and PO3 (left panel).

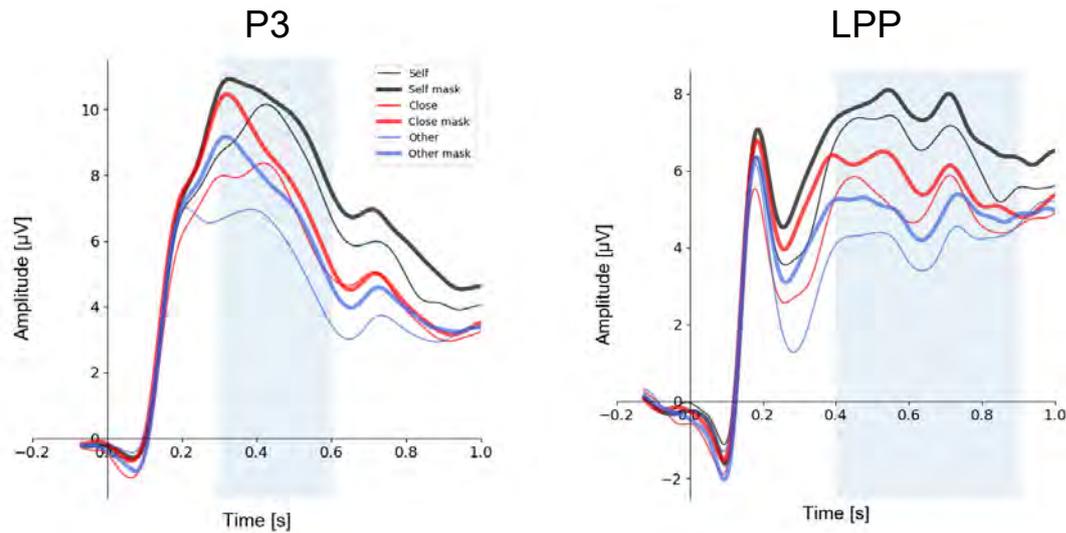


Figure 5. Late ERP components, P3 and LPP. In the left panel, we observe the P3 component, calculated from pooled electrodes Pz, CPz, CP2, and P2. In the right panel, we present the LPP derived from pooled electrodes FCz, Fz, FC2, and C2. The selected electrodes for both potentials were located within the region of maximal activity in the topographical distribution of brain activity. The analysed time light-blue rectangles indicate windows.

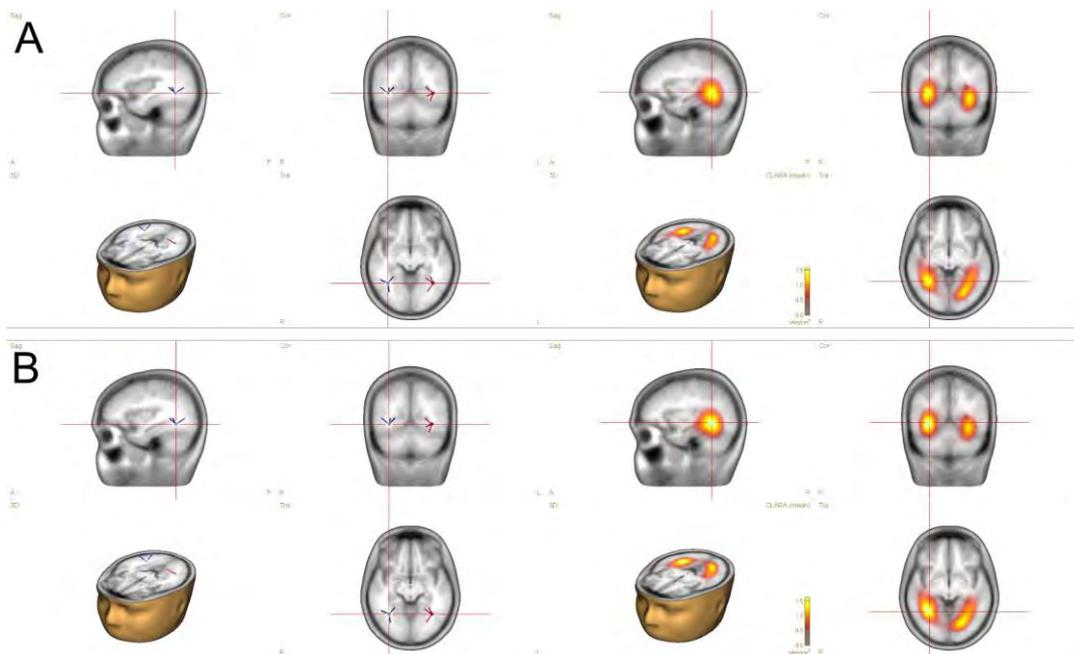


Figure 6. Source analysis of ERP responses was conducted (in a typical time window for N170) using distributed source imaging with CLARA (Classical LORETA Analysis Recursively Applied). The results indicate that the fusiform gyrus is the primary signal source elicited by presenting masked faces (Panel A) and unmasked faces (Panel B). Two dipoles fitted within the fusiform gyrus explain nearly 98% of the data.

Considering these results, it might be assumed that subjective emotionality plays a role in SPE as the processing of close-other's and unknown faces was disparate. However, the dissociation in the processing of close-other's and one's own faces also manifested; one may assume that self-face is more imbued with subjective emotionality, or it is better known to an individual, suggesting the more crucial role of the familiarity factor. Additionally, it seems that the recognition of human faces is not severely disturbed by the COVID-19 restrictions and even partial information about the self-face leads to the emergence of SPE.

3.2. Familiarity

Despite the fact that numerous studies were devoted to the familiarity factor, they are based on similar methodologies. Scrutinising the familiarity factor, studies typically compared reactions to the self-related stimuli and stimuli related to the other person/people (celebrities: Zhou et al., 2020; family or friends: Cygan et al., 2014; Cygan et al., 2022). As stimuli, most often were used faces (Cygan et al., 2022) and sometimes names (Perrin et al., 2005) or parts of the body (Ferri et al., 2012). The research findings consistently show the presence of SPE, which is interpreted in favour of familiarity. However, it seems to be overlooked that not only familiarity differentiates those stimuli but also emotionality, as they cannot be defined only by one of these factors. Therefore, such a choice of stimuli disallows disentangle and analyse the source of self-prioritisation.

Sui and colleagues (2012) essayed to split the wreath of these two factors by proposing a novel approach. Instead of looking for stimuli presenting different levels of familiarity, they obliterated it in all employed stimuli. In their experimental paradigm, participants were told to make associations between unknown, neutral stimuli (three geometric shapes) and personally significant labels (you, friend, stranger). In this manner, stimuli with the same level of familiarity were filled with different emotional intensity. Participants were tasked with answering whether the displayed shape-label pair matched the learned assignment. The findings of this study showed that participants were faster and more accurate in the detection of congruent self-shape-label pairs than any other combination. It suggests that SPE extends the frames of familiarity and may be driven by emotionality. This effect was replicated in numerous studies (e.g. Sui et al., 2014), however, all of them were based on behavioural measures (RTs accuracy), obtained in perceptual matching task. Nonetheless, some scientists imply the overlooked presence and plausible impact of simultaneously displayed labels (Woźniak and Knoblich, 2019). It sowed doubt whether the SPE was a result of the association of the unknown stimuli with the self or was again an effect of high familiarity and emotionality factors combination hidden in the verbal labels.

The aim of the third study, presented in this thesis, was to investigate the role of familiarity factor. In pursuit of detailed assessment, stimuli were set on the two extremes of the familiarity spectrum. As the highly familiar stimuli were used faces of the self and a close-other, and as the newly acquired ones - unknown abstract shapes that were just newly assigned to one's own person and the freely chosen close-other. As the control

conditions to the self and close-other's conditions, unknown neutral stimuli were used (unknown faces and unknown shapes, respectively). The task was as follows: participants were told to indicate whether the presented stimuli were familiar or unfamiliar (Figure 7). Familiar stimuli incorporated (1) the faces of a participant and a chosen close-other and (2) the shapes assigned to them just before the study.

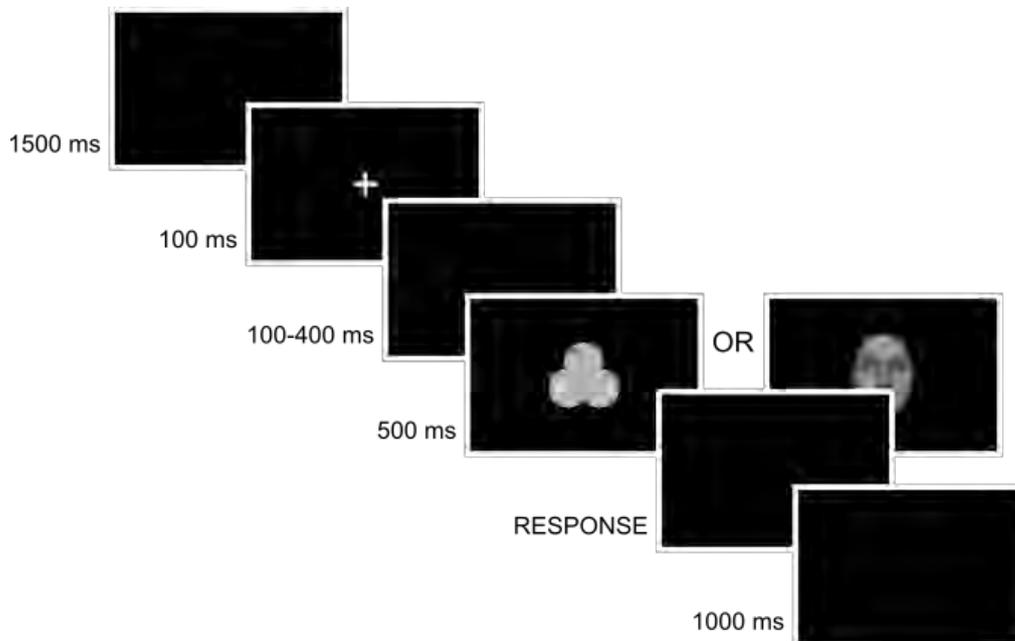


Figure 7. Schematic presentation of the experimental procedure: Three categories of faces (self, close-other's, unknown) and three categories of shapes (self-assigned, assigned to the close-other, unknown) were intermixed and presented in a pseudo-random order. Participants were instructed to determine whether each stimulus was familiar or not.

For faces, a typical pattern was observed. Self-face evoked significantly enhanced P3 amplitude than all other faces (i.e., close-other's and unknown faces) (Figure 8). P3 amplitude was significantly smaller for unknown faces than for both familiar faces. Responses to close-other's face were located in between, significantly different from self-face and unknown faces. Moreover, self- and close-other's faces presented a distinct processing pattern, as the cluster-based permutation test revealed differences between those and unknown faces, widely distributed in space and time (Figure 9).

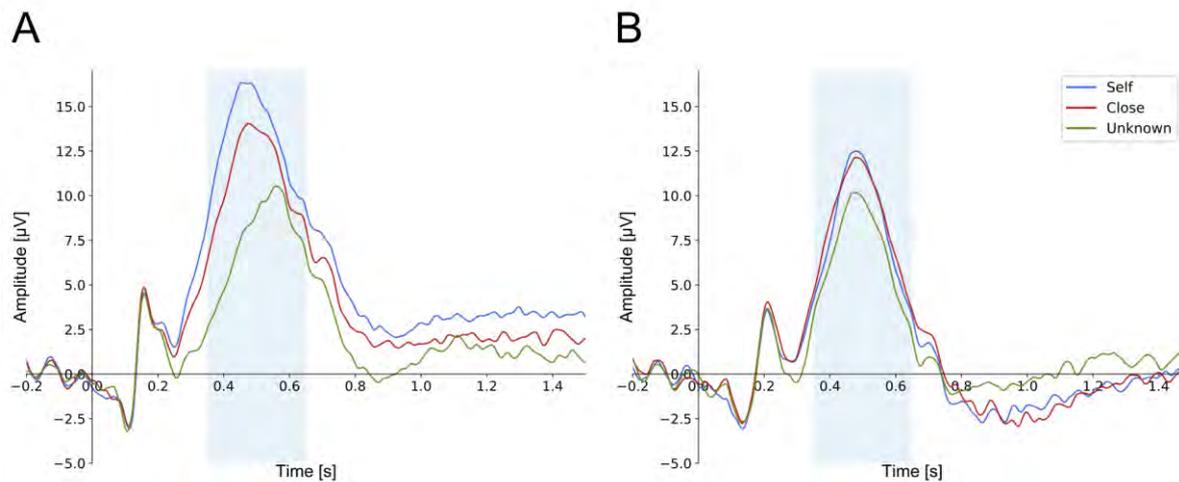


Figure 8. Grand-average ERPs for (A) faces and (B) shapes, combined from four electrodes: CP1, CPz, CP2, and Pz. The analysed time window of P3 is highlighted with light-blue rectangles.

Crucially, P3 amplitudes to shapes assigned to the self and close-other were likewise elevated (the differences between them were non-significant), however, in both cases, they were larger than to the unknown shapes (Figure 8). This was reinforced by the cluster-based permutation tests: self-assigned shape and shape assigned to the close-other were processed in a similar manner as no cluster was detected in the whole analysed time window. The processing of both shapes differed significantly from the processing of unknown shapes (Figure 10).

Last but not least, shapes were compared with faces. Substantially heightened P3 amplitudes were observed for self-face and close-other's face than for shapes assigned to the self and close-other, respectively. For unknown faces and shapes, no differences in P3 amplitudes were unveiled.

The findings of this study underlines the significance of familiarity. As the familiarity of presented stimuli was equalised, the SPE vanished.

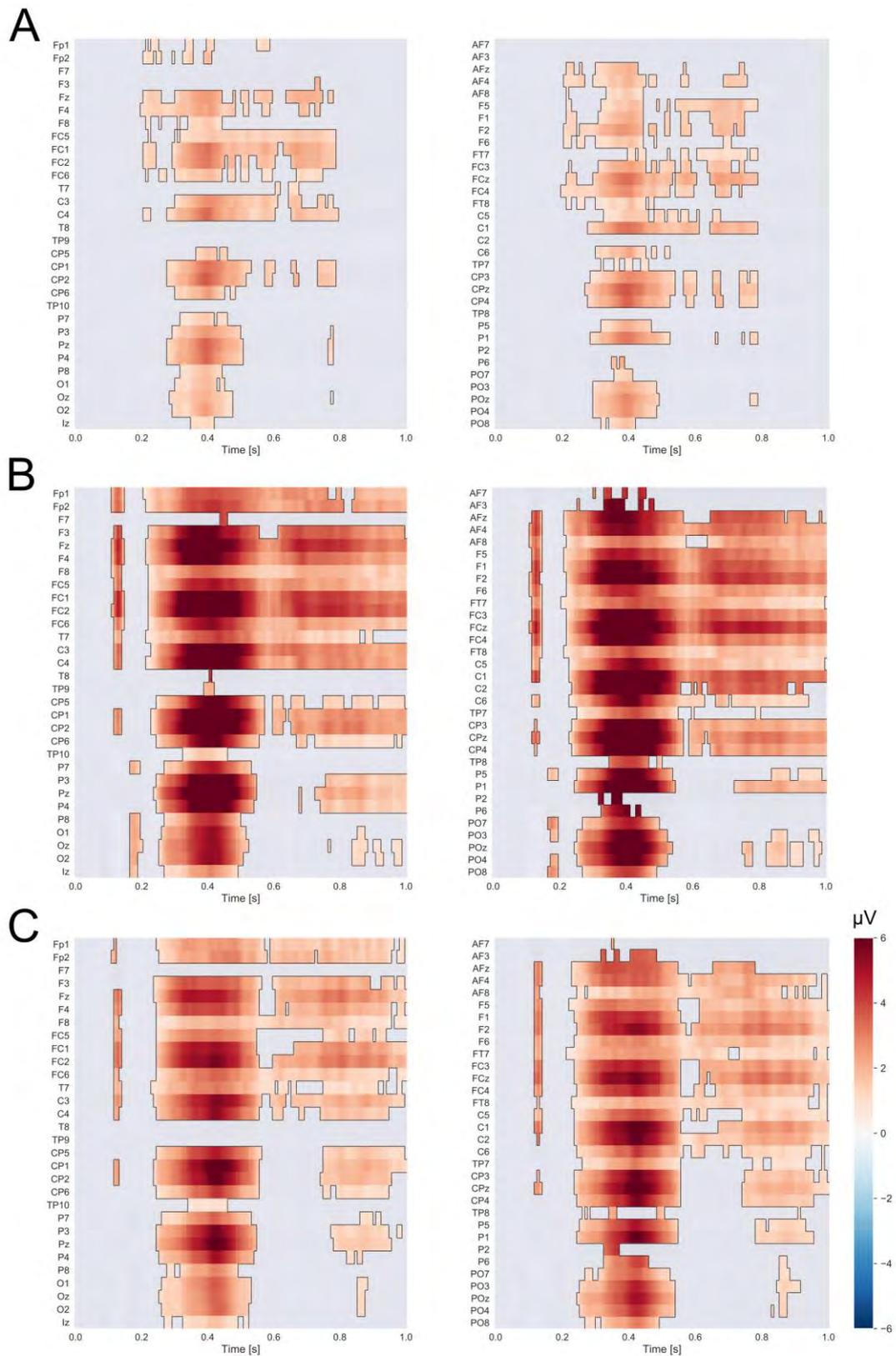


Figure 9. The outcomes of cluster-based permutation tests conducted on faces: Comparisons include the self-face versus (A) the close-other and (B) unknown faces, as well as (C) the face of the close-other versus unknown. Any statistically significant positive distinctions between these conditions are highlighted in red ($p < .05$).

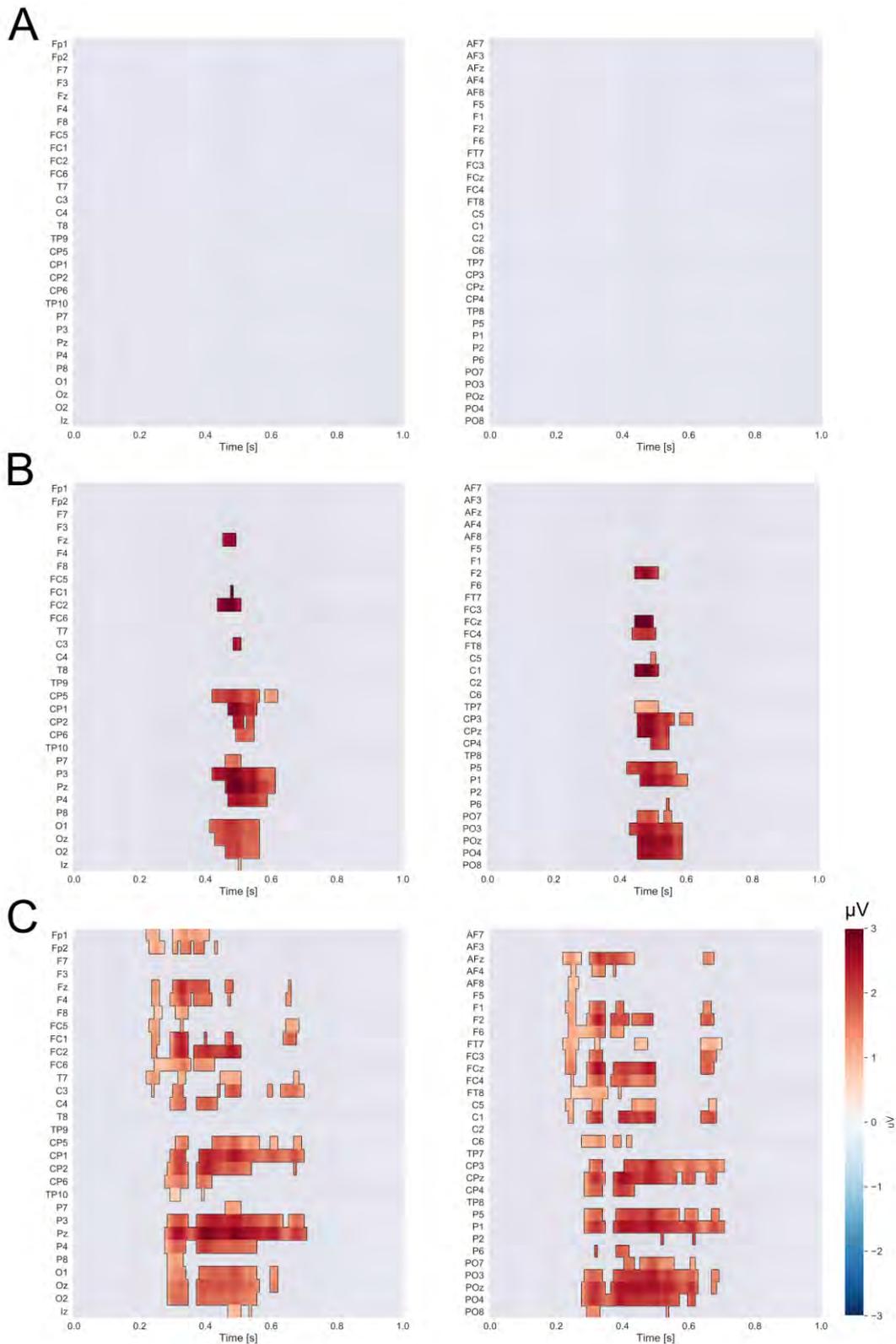


Figure 10. The outcomes of cluster-based permutation tests conducted on shape data: Comparisons include the self-assigned shape versus the shape assigned to (A) the close-other and (B) unknown shapes, as well as (C) the shape assigned to the close-other versus unknown shapes. Any statistically significant positive distinctions between these conditions are highlighted in red ($p < .05$).

4. Discussion

As humans, we are quite inquiring beings. Some are dedicated to exploring the intricacies of the world, while others are deeply engrossed in the matters of the inner self and consciousness. Nonetheless, despite the profound interest of many distinct disciplines in exploring the self, some answers are still unearthed. Therefore, this thesis focused on the factors leading to self-prioritisation as they remain ambiguous. Pursuing to unveil the significance of familiarity and emotionality, a human face was chosen as the main stimulus in my research. Although self-prioritisation is observed for other self-related stimuli (for instance, a name) (e.g. Cygan et al., 2014), a face cannot be shared with other people, thus, it is clearly related only to the self and is even seen as its emblem (McNeill, 1998).

In general, the SPE was clearly evidenced in the case of one's own face. Specifically, P3 and LPP amplitudes were significantly more enhanced for the self-face than for all other (close-other's, unknown emotional, and neutral) faces. These findings are in line with the previous studies, reporting the SPE for one's own face (Wójcik et al., 2018; Kotlewska et al., 2017), even when compared with faces of personally familiar people (Cygan et al., 2014; Kotlewska and Nowicka, 2015; Kotlewska and Nowicka, 2016). However, it is worth stressing that only one earlier ERP study investigated the processing of self-face and emotionally negative faces, all presented as deviant stimuli in an odd-ball procedure (Zhu et al., 2016). Despite different experimental procedures, an analogous pattern of findings was reported: amplitudes of P3 to the self-face were much higher than to (unknown) emotional and neutral faces. In addition, results presented in this thesis showed that P3 amplitude was also significantly increased for the close-other's face compared to the unknown neutral faces. This pattern of P3 results may be driven by the familiarity of faces. Moreover, it may be interpreted with respect to the classical models of face recognition (Bruce and Young, 1986; Burton et al., 1990).

Classical models of face recognition suggest four stages: (1) structural encoding, (2) FRUs - face recognition units, (3) PINs - person identity nodes, and (4) SIUs - semantic information units. After the structural encoding of the crucial face features, a structural representation of the face is triggered (FRU) if it is perceived as known. The next step initiates a multimodal representation of the seen person (PIN), leading to full identification. This enables activation of the last phase - the retrieval of the possessed biographical knowledge about the recognised individual (SIUs). According to this concept, some studies have linked different ERP

components with enumerated stages, viewing late ERP components as a reflection of PINs' and SIUs' phases (Paller et al., 2000; Tacikowski et al., 2011). Therefore, significantly higher amplitudes of P3 for the self-face, when compared to all other (i.e., close-other's, unknown emotional and neutral) faces, may arise from hugely rich semantic information for the self. Analogously, substantially higher P3 amplitude for the close-other's face in comparison to the unknown neutral faces may also result from available semantic information for the close-other in contrast to the unknown person. Building upon this interpretation, the lack of differences between emotional and neutral faces does not stun, as no semantic knowledge is accessible. Thus, more familiar faces evoke higher P3 amplitudes.

Nevertheless, we can broaden the angle of interpretation and look at self-prioritisation and these results, for instance, through the lens of attentional processes. Automatic capture and prioritised allocation of attention to the self-referential stimuli are plausible mechanisms that actuate or trigger the self-prioritisation process (Humphreys and Sui, 2016; Sui and Rotshtein, 2019). Humphreys and Sui (2016) provided a framework primarily situated within the attentional domain that aimed at explaining the prioritised processing of self-referential information (the Self Attention Network – SAN). Specifically, the SAN states that self-related attentional processing is in some way special. The SAN framework is based on the notion that an individual's self-representation is continuously activated and is thus rapidly triggered by the presence of a self-representational stimulus. Therefore, the prioritised processing of self-referential information could be explained by the rapid engagement of bottom-up orienting processes stemming from a chronically activated self-schema. In light of the latter, it is worth noting that P3 is often related to the attentional processes (e.g. Polich, 2007). Thus, this interpretation seems to be cogent as numerous studies demonstrated that one's own face captivated attention automatically (Tong and Nakayama, 1999; Brédart et al., 2006; Alzueta et al., 2020) and similarly evoked a significant increase in P3 amplitude (Knyazev, 2013). Therefore, the significant P3 growth in response to the self-face (and later, in the order of increase, to the close-other's face) may indicate the preferential attention engagement, shifting the tipping point from the later attentional facilitation as a consequence of rich semantic information.

Another concept that could shed light on the obtained results is the size of the saliency of presented stimuli in all three studies. Comparison of the self-face with any emotional unknown faces revealed no similarities in any of the shown dimensions - neither in the ERP results nor the cluster-based permutation tests. Processing of the self-face also differed

from processing the close-other's face. Thus, despite all these faces seeming salient when compared to the unknown neutral face, they were no more in comparison to the self-face. This pattern of results indicates that the saliency might be contextual. In fact, studies show that P3 (Teixeira et al., 2010), as well as LPP (Martin et al., 2020), are influenced by saliency. While studies comparing unknown emotional vs neutral faces report significant differences between them (Zhu et al., 2016), our findings showed that when the self-face was added to the set of presented stimuli, that difference disappeared. Thus, reported P3 and LPP findings may indicate that the self-face and close-other's face are more salient than objectively emotional faces. Moreover, it is worth paying attention to the position of the close-other's face in the ERPs results hierarchy for a more profound and complex understanding of self-prioritisation. As the close-other's face was between the self-face and unknown neutral face, its P3 amplitude differed significantly from both. In contrast, its LPP amplitude was distinctive only from the self-face, i.e. LPP amplitudes for the close-other and unknown person were similar. Studies associate LPP with emotional arousal as it is enhanced for emotional stimuli in comparison to the neutral stimuli (Foti and Hajcak, 2008; Olofsson et al., 2008; Cuthbert et al., 2000), and the growth of its amplitude is correlated with the growth of arousal (Cuthbert et al., 2000). Some studies compared the self-face with the close-other's face, showing a similar pattern of P3 findings (Kotowska and Nowicka, 2015; Kotowska and Nowicka, 2016). As aforementioned, P3 is usually related to attentional processes and might be modulated by the saliency of the stimuli (Teixeira et al., 2010), similar to the LPP, which is typically associated with emotional saliency (Cuthbert et al., 2000). It seems possible that the close-other's face, which presents a mixture of high familiarity and high emotionality, may attract attention, but its emotional load is not high enough to maintain this effect in time. Therefore, this would indicate familiarity as the main factor of self-prioritisation. However, this is a quite venturesome hypothesis and further examination dedicated to this aspect is required.

Moreover, the results of the second study have unveiled the presence of SPE in the extraordinary conditions caused by the COVID-19 pandemic, i.e. for the self-face covered by mask. Other studies focused on the perception of faces covered by the surgical-like mask revealed agreeably difficulties in face-matching performance tasks when compared to fully visible faces (Freud et al., 2020; Carragher and Hancock, 2020; Noyes et al., 2021; Estudillo et al., 2021). Moreover, they discovered that covering faces with a surgical-like mask hits the face-matching performance similarly, regardless of the familiarity

of the perceived faces (Carragher and Hancock, 2020; Noyes et al., 2021). Despite the distinctive paradigms and methods of data collection, our results are in line with those from the previous studies. P1, P3, and LPP amplitudes were significantly higher for each face hidden behind the surgical-like mask, i.e. all faces (self-face, close-other's, and unknown faces) were similarly affected, and they attracted attention to a higher extent than uncovered faces. Nevertheless, the pattern of findings observed in our study with covered faces (self-, close-other's, unknown) is analogous to the typical pattern for uncovered faces: presentations of the self-face were associated with increased P3 and LPP amplitude. In other words, the SPE was found in the case of partial information about the self- and other faces. The latter is a novel finding, and it expands our knowledge about the SPE. An interesting insight is also provided by the source analysis, which demonstrated similar structural activation for both stimulus types, i.e. faces covered and uncovered by masks. Such a pattern of findings further supports the notion that faces are similarly processed regardless of available facial information.

In the last study, faces evoked higher ERP responses than shapes, indicating that the former captures attention stronger than the latter. However, the pattern of results for shapes was dissimilar to that of faces. A comparison of collected data revealed that shapes assigned to the participant and chosen close-other did not differ, however, both presented significantly higher P3 amplitudes and were characterised by distinctive activation patterns from unknown shapes. It should be highlighted that the association of the shapes consisted of remembering them, thus, they were equally familiar and more familiar than any other shape used later in the study. Therefore, the observed difference between assigned and unknown shapes, and the lack of such differences between the former ones, is a strong argument for familiarity.

Nonetheless, our results are diverse from those obtained in other studies assigning unknown stimuli to the self and close-other. It may result from methodological differences. Sui and colleagues (2012) used a shape-label matching task in which participants were asked to indicate whether the presented pair was congruent or not. Woźniak et al. (2018) designed a task matching labels and unknown faces, earlier assigned to the self and others. As in both of these studies, well-known labels were used, it is possible that reported SPE was a consequence of labels instead of transferred emotionality on those stimuli. Moreover, the main question was significantly different - in the aforementioned experiments, participants were tasked to focus on the stimuli' congruency, whereas in this study, it was on familiarity.

5. Summary and Conclusions

Results of these studies clearly indicated higher amplitudes of late (P3 and LPP) ERP components to self-face vs. subjectively and objectively emotional faces, pointing to the role of familiarity factor in the SPE. Crucially, when the familiarity of processed stimuli is equalised (abstract shapes), the SPE disappears.

Thus, the key conclusion drawn from this thesis is that familiarity plays a crucial role in driving the self-prioritisation effect. Through a comprehensive exploration, we consistently demonstrate the pivotal role of high familiarity of self-related information for the appearance of the self-prioritisation effect. This work further advances our scientific understanding by spotlighting the intricate interplay between familiarity and emotionality in shaping how individuals process information and make decisions influenced by the self-prioritisation effect.

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oświadczam, że mój wkład w powstanie tej publikacji polegał na:

- współdziałanie w zaprojektowaniu badania
- opracowaniu procedury eksperymentalnej
- napisaniu skryptu w PRESENTATION do prezentacji bodźców wzrokowych z zaprogramowaniem losowej sekwencji bodźców oraz z wysyłaniem znaczników bodźców do oprogramowania rejestrującego sygnał EEG
- przygotowaniu indywidualnego zestawu bodźców wzrokowych dla każdej osoby badanej (wchodziły w ten zestaw m. in. zdjęcia twarzy własnej i twarzy emocjonalne, które musiały być dopasowane do założonego rozmiaru, wyrównana musiała być ich luminacja i kontrast)
- rekrutacji osób badanych
- przeprowadzeniu wszystkich badań z rejestracją EEG
- analizie danych elektrofizjologicznych z wykorzystaniem metody potencjałów wywołanych
- analizie statystycznej amplitud potencjałów wywołanych
- analizie statystycznej danych behawioralnych
- współdziałanie w interpretacji i dyskusji wyników
- opisanie procedury i metody
- zaplanowaniu prezentacji graficznej uzyskanych wyników
- współdziałanie w pisaniu wstępnej wersji wstępu i dyskusji
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oświadczam, że mój wkład w powstanie tej publikacji polegał na konsultowaniu schematu doświadczenia, pomocy technicznej w przeprowadzeniu części badań z rejestracją EEG, konsultowaniu analizy komponent P3 i LPP, współudziale w przeprowadzeniu części analiz (testy permutacyjne, analiza podobieństw reprezentacji), oraz współudziale w korekcie opisu powyższych metod oraz opracowaniu graficznym rycin do publikacji.

Jednocześnie wyrażam zgodę na przedłożenie w/w pracy przez mgr Annę Żochowską jako części rozprawy doktorskiej w formie spójnego tematycznie cyklu artykułów opublikowanych w czasopismach naukowych.



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oświadczam, że mój wkład w powstanie tej publikacji polegał na konsultowaniu doboru bodźców wzrokowych, współdziałale w przeprowadzeniu części analiz (testy permutacyjne, analiza podobieństw reprezentacji), oraz współdziałale w korekcie opisu powyższych metod.

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oświadczam, że publikacja ta powstała w ramach realizacji kierowanego przeze mnie grantu OPUS (nr 2018/31/B/HS6/00461). Moja rola w powstaniu tej publikacji polegała na ustaleniu koncepcji badania i zaprojektowaniu schematu badania, sprawowaniu nadzoru merytorycznego, konsultowaniu analizy danych, dyskusji i interpretacji uzyskanych wyników oraz współudziale w pisaniu manuskryptu.



Self-face and emotional faces—are they alike?

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Abstract

The image of one's own face is a particularly distinctive feature of the self. The self-face differs from other faces not only in respect of its familiarity but also in respect of its subjective emotional significance and saliency. The current study aimed at elucidating similarities/dissimilarities between processing of one's own face and emotional faces: happy faces (based on the self-positive bias) and fearful faces (because of their high perceptual saliency, a feature shared with self-face). Electroencephalogram data were collected in the group of 30 participants who performed a simple detection task. Event-related potential analyses indicated significantly increased P3 and late positive potential amplitudes to the self-face in comparison to all other faces: fearful, happy and neutral. Permutation tests confirmed the differences between the self-face and all three types of other faces for numerous electrode sites and in broad time windows. Representational similarity analysis, in turn, revealed distinct processing of the self-face and did not provide any evidence in favour of similarities between the self-face and emotional (either negative or positive) faces. These findings strongly suggest that the self-face processing do not resemble those of emotional faces, thus implying that prioritized self-referential processing is driven by the subjective relevance of one's own face.

Key words: self; emotion; familiarity; ERP; RSA

Introduction

The self-face—as a unique piece of self-referential information—is strongly linked to the physical self-identity (McNeill, 1998; Estudillo, 2017). Within the vast number of faces encountered during everyday life, there is perhaps no face that has more meaning to us than our own face. It has even been suggested that the image of one's own face may trigger the sense of self-awareness in general (Keenan *et al.*, 2005; Devue and Brédart, 2008). A growing literature shows the prioritized processing of that stimulus and provides converging lines of evidence indicating that one's own face captures attention in various conditions and on different levels of processing (for review see: Humphreys and Sui, 2016).

There is an ongoing discussion whether the prioritized processing of the self-face is a consequence of its high familiarity, resulting from frequent exposure to one's own image in mirrors and on photographs (e.g. Bortolon *et al.*, 2018). Numerous studies have compared processing of the self-face to the processing of faces that are less familiar. For instance, behavioural studies have shown that when participants were asked to classify faces as belonging to themselves, a friend or a stranger, classification of the self-face was much faster than classification of the other's faces (Keyes and Brady, 2010; Keyes, 2012). Moreover, a stronger interference was generated by a self-face flanking a classmate's name in comparison to the reverse condition, i.e. a classmate's face flanking a self-name (Brédart *et al.*, 2006). The self-face was

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also more quickly detected amongst distracters than a stranger's face, even if it was presented in an atypical orientation and after hundreds of trials (Tong and Nakayama, 1999). Functional magnetic resonance imaging (fMRI) studies revealed increased activation of neural regions, such as the medial prefrontal cortex and anterior cingulate cortex, to images of one's own face when compared with other's faces (Keenan et al., 2000; Kircher et al., 2001; Heatherton et al., 2006). Event-related potential (ERP) studies, in turn, showed that brain activity associated with self-face processing is enhanced compared to the processing of familiar, famous and unknown faces (Keyes and Brady, 2010; Miyakoshi et al., 2010; Tacikowski and Nowicka, 2010; Tacikowski et al., 2011; Cygan et al., 2014; Kotlewska and Nowicka, 2015; Alzueta et al., 2019). Those results may be viewed as evidence that the pre-experimental familiarity of processed faces determines a commonly reported pattern of findings: the strongest brain responses to the self-face (i.e. extremely familiar face) and the weakest to unknown faces, with familiar/famous faces in between (e.g. Tacikowski and Nowicka, 2010).

However, the notion of the extreme familiarity of the self-face as the driving factor of its special processing status is undermined by experiments revealing that even abstract stimuli arbitrarily associated with the self during the experiment benefit from a robust prioritization effect despite previously being both unfamiliar and self-irrelevant (e.g. Sui et al., 2012, 2014). In a similar manner, an unfamiliar face that was also arbitrary associated with the self can be preferentially processed (Woźniak et al., 2018). In that study, three unfamiliar faces were introduced with the labels 'you', 'friend' and 'stranger.' Afterwards, participants were required to assess whether two stimuli presented in succession (i.e. face and label) matched. If the first stimulus (either the 'new' face or the label) referred to the self, reaction times (RTs) were faster. The prioritized processing of initially unfamiliar stimuli—that do not have an intrinsic relation but an acquired relation to the self—seems to contradict the notion that familiarity is the driving factor of preferential self-referential processing. In addition, there is evidence that the self-face is preferentially processed even when compared with faces that share a similar level of familiarity; this includes a close-other's face, e.g. mother's, father's, sibling's, partner's, etc. (Cygan et al., 2014; Kotlewska and Nowicka, 2015; Kotlewska et al., 2017), and the faces of dizygotic twins (Butler et al., 2013).

Finally, in a recent meta-analysis study, RTs for the self-face were compared with RTs for other faces across a large number of studies (Bortolon and Raffard, 2018). The tested moderators included the familiarity (i.e. whether the face was familiar or not to the participants) and identity of faces (i.e. whether the face belonged to someone personally known by participants or whether it was a famous person or a stranger). The results of that study illustrate that RTs were substantially shorter in response to the self-face than to other faces in general. However, none of the two aforementioned moderators had an impact on this RT effect (Bortolon and Raffard, 2018). Altogether, the mentioned findings may suggest the involvement of factors other than familiarity in the preferential processing of the self-face.

It is worth noting that self-related stimuli differ from stimuli referring to other people not only in respect of their familiarity levels but also in respect of their subjective emotional relevance. Current definitions of emotions emphasize their subjective character (e.g. Dolan, 2002). Therefore, it is the personal relevance of a particular stimulus that determines its emotional vs neutral evaluation. In contrast to the familiarity factor, the role of emotional aspects in prioritized self-face processing has gained much less empirical attention. However, there is indirect

evidence suggesting some substantial similarities in the processing of one's own face and emotional faces. For instance, both types of faces capture, hold and bias attention (Eimer and Kiss, 2007; Wieser et al., 2018; Wójcik et al., 2018, 2019). In addition, both emotional faces and the self-face can be processed without awareness (Zotto and Pegna, 2015; Wójcik et al., 2019). Those findings may suggest that the self-face, like emotional faces, can be treated as a salient stimulus.

The processing of both of these stimuli shares similar neuronal implementations (Northoff, 2016). Specifically, similar patterns of ERP findings were observed for the self-face compared to other faces and emotional faces compared to neutral faces. In both cases significantly enhanced amplitudes of late ERP components were typically reported, both to the self-face and emotional faces (e.g. Luo et al., 2010; Tacikowski and Nowicka, 2010; Kotlewska and Nowicka, 2015). Moreover, the processing of any type of emotion, either positive or negative, was shown to activate the anterior cortical midline structures as well as the ventromedial and dorsomedial prefrontal cortex (e.g. Phan et al., 2002; Etkin et al., 2011; Roy et al., 2012; Rolls, 2019), i.e. the very same regions recruited in various self-referential processes (e.g. Moran et al., 2006; Northoff et al., 2009), including self-recognition (Keenan et al., 2000, 2001; Kircher et al., 2001; Heatherton et al., 2006). This overlap may indicate that exposure to self-face induces both introspection and emotional reactions effectively. In a similar vein, it was proposed (Devue and Brédart, 2011) that self-recognition preceded by the perception of one's own face may cause a cascade of higher-order cognitive operations: information that is identified as related to oneself can be evaluated in terms of its relevance to current goals, expectations, etc. The result of such an evaluation may be accompanied by emotional responses (Craver, 2003; Morita et al., 2008).

The goal of the present ERP study was to directly compare the neural correlates of self-face and emotional face processing. On the basis of the self-positivity bias (Greenwald, 1980; Watson et al., 2007) and the theory of implicit positive association (IPA) with the self (Ma and Han, 2010), one may assume that self-face is treated and processed like an emotionally positive face (i.e. a happy/smiling face). The self-positivity bias is one of the most common findings in social psychology (Dunning et al., 2004; Alicke et al., 2005). It has been found that people have a basic desire to feel good about themselves (James, 1890/1950) and possess a rather positive view of the self (Greenwald, 1980). More specifically, when being asked to describe one's own personality, participants typically assign themselves more positive than negative personality adjectives (Alicke, 1985; Kwan et al., 2007; Zhang et al., 2013). This effect is accompanied by shorter RTs to positive self-descriptive words as compared to negative self-descriptive words (Watson et al., 2007). This positivity bias is also reflected in memory processes, as the recall of positive personal information is much easier and more efficient than the recall of negative personal information (Kuiper and MacDonald, 1982). In addition, positive self-face evaluation is associated with the activation of posterior parts of the cingulate cortex, a brain region that varies in activity with arousal state (Leech and Sharp, 2014) and is correlated with self-esteem measures (Oikawa et al., 2012). The self-positivity bias is quite robust and has been obtained across a diverse representation of samples, varying in age, gender, psychopathology and culture (Brown and Kobayashi, 2002; Sedikides et al., 2003; Mezulis et al., 2004). However, in most cases positive self-association occurs unconsciously or in an implicit mode (Greenwald and Banaji, 1995; Jones et al., 2002). While the self-positivity bias refers to many self-related domains, the IPA theory is focused on self-face processing. Its key assumption

is that an IPA with the self mediates its advantage in face recognition, i.e. the process of recognizing one's own face activates positive attributes in the self-concept, which facilitates responses to the self-face and thus results in a self-advantage in face recognition.

However, if saliency of the self-face is the primary driving factor of prioritized processing, it would imply a similar processing of the self-face and other salient faces, i.e. fearful faces. Fearful faces (emotive social stimuli) that effectively capture our attention (Troiani et al., 2014) are processed with priority and have a privileged access to awareness (Stein et al., 2014). This is also the case for the self-face (Wójcik et al., 2018, 2019). For these reasons, it is possible that faces sharing such an extreme saliency feature could be processed similarly at the neural level. Therefore, in the current electroencephalogram (EEG) study, the processing of the self-face and emotionally positive and emotionally negative faces was investigated. In addition, neutral faces were introduced as control stimuli. This allowed us to address the question of whether the effects observed for the self-face and emotional faces can be explained by the saliency of faces in general. The task was a simple detection of the mentioned stimuli.

The analysis of ERPs was focused on ERP components commonly reported in studies with self-referential and/or emotional stimuli: P3—a positive ERP component occurring around 300 ms after the stimulus onset, with its maximum over central-parietal scalp sites (Tacikowski and Nowicka, 2010), and the late positive potential (LPP)—a positive, sustained ERP component starting around 500 ms after stimulus onset with a wide (frontal-central-parietal) topography (Kotłowska and Nowicka, 2016; Grecucci et al., 2019). The functional role of P3 is associated mainly with attentional resource allocation (Polich, 2007). Increased P3 amplitudes have been found for both the self-face (e.g. Tacikowski and Nowicka, 2010; Kotłowska and Nowicka, 2015) and emotional faces (e.g. Luo et al., 2010). Enhanced LPP, in turn, has most often been reported in studies investigating the processing of emotional and neutral faces (e.g. Schupp et al., 2004; Herbert et al., 2013; Zhang et al., 2018), but it was also observed in the case of self-face processing (Zhong et al., 2016). LPP reflects a spatially non-specific (i.e. global) temporary increase in attention that serves to facilitate the processing of the affective stimulus that elicited the LPP (Brown et al., 2012).

We hypothesized that P3 and LPP to the self-faces would be significantly enhanced in comparison to neutral faces. As far as the relation between the self-face and emotionally positive and negative faces is concerned, we did not have any specific a priori expectations about the direction of the effect. Thus, we aimed at exploring this issue using different methods of EEG data analysis in addition to ERPs.

Hence, the collected EEG data were also analysed using a data-analytical framework called representational similarity analysis (RSA; Kriegeskorte et al., 2008). RSA enables abstracting from the activity patterns themselves. Instead, multi-channel measures of neural activity are quantitatively related to each other and to a computational theory by comparing representational dissimilarity matrices that characterize the information carried by a given representation in a brain or model. As emotional faces and the self-face may elicit distinct spatial patterns of activity, a method that allows us to probe the EEG for similarities/dissimilarities in distributed neuronal codes complements the standard univariate approach. More specifically, RSA is a multivariate approach that accesses distributed information that would normally be lost through averaging procedures. In

addition, it allows to test models in which variables can overlap or are represented in distinct states. Taken as a whole, this suggests that this method is perfectly suited for comparing the neuronal correlates of self-face processing and the processing of emotional faces in order to establish plausible commonalities in the spatial distribution of activity.

In addition to the similarity/dissimilarity metric obtained by applying RSA, the distinct spatial patterns of activity elicited by different types of faces were also tested with spatio-temporal cluster-based permutation tests (Maris and Oostenveld, 2007). This method enables unbiased comparisons of EEG signal recorded in different experimental conditions at all sensors and all time points while controlling for multiple comparisons and maximizing power by employing the cluster structure of the data as its sole test statistic. We used this approach to test for differences in spatial and temporal distributions between experimental conditions. Altogether, ERP, RSA and permutation test findings complement each other, providing a global and complete view of commonality/distinctiveness in the neural underpinnings of self-face and emotional faces processing.

It is worth noting that this approach, i.e. using different methods of EEG data analysis, can be seen in the context of the multiverse analysis approach (Steen et al., 2016). It has been argued that going beyond a single analysis of the experimental data should become a standard practice, and instead of analysing the data set with one method, researchers should perform multiple analyses on the same data set. In this way, findings obtained in one type of analysis could be confronted with findings from different methods, thus confirming (or undermining) conclusions drawn from the initial analysis.

Materials and methods

Participants

Thirty participants (16 females and 14 males) between the ages of 20 and 33 ($M = 26.033$; $s.d. = 3.045$) took part in the study. All participants were right-handed as verified with the Edinburgh Handedness Inventory (Oldfield, 1971). Only participants with normal or corrected-to-normal vision with the use of contacts and with no distinctive facial marks were recruited. This restriction was introduced to ensure the uniformity of visual stimuli standards, as the photograph of every participant was matched with photographs from the Karolinska Directed Emotional Faces (KDEF) database (Lundqvist et al., 1998). Images included in this database present faces without glasses and without any visible marks. All participants reported no history of mental or neurological diseases. The required sample size was estimated using the G*Power 3 software (Faul et al., 2007). The analysis was conducted for a one-way repeated-measures analysis of variance (ANOVA) with four measurement levels (estimated effect size $f = 0.25$, $\alpha = 0.05$, $\beta = 0.90$, and non-sphericity correction $\epsilon = 1.0$). It yielded a sample size of 30 participants. One data set, however, had to be excluded from the sample during preprocessing based on a technical malfunction.

Ethics statement

The human ethics committee of the SWPS University of Social Sciences and Humanities (Warsaw, Poland) approved the experimental protocol. Written informed consent was obtained from each participant prior to the study and all participants received financial compensation for their participation.

Stimuli

In the current study, similar to our previous studies on the topic of self-face processing, the set of stimuli was individually tailored for each participant (Tacikowski and Nowicka, 2010; Tacikowski et al., 2011; Cygan et al., 2014; Kotlewska and Nowicka, 2015; Kotlewska et al., 2017; Wójcik et al., 2018, 2019). It consisted of single face images of four types: the self-face, an emotionally negative (fearful) face, an emotionally positive (happy) face and a neutral face. Self-face photographs were taken prior to the experiment. All participants were invited to the lab to have a photograph of their face taken in a standardized environment (the same background and lightning conditions). Participants were asked to maintain a neutral facial expression when photographed. Photographs of emotional and neutral faces were taken from the A or B series of the KDEF database (Lundqvist et al., 1998). To ensure that neutral and emotional facial expressions were recognized, we selected actors on the basis of the unbiased hit rates of detection (Goeleven et al., 2008). The gender of faces from the KDEF database was matched to each subject's gender in order to control for the between-category variability. Different images of emotional and neutral faces were used in individual sets of stimuli in order to avoid the plausible influence of one selected image on a pattern of brain activity. In each stimuli set, the KDEF images represented three different identities, i.e. if an image of a happy face of a given actor was selected, the images of fearful and neutral faces came from two different actors. Pictures within each stimuli set (i.e. the self-face image and selected KDEF images) were extracted from the background, grey-scaled, cropped to include only the facial features (i.e. the face oval without hair), resized to subtend $6.7^\circ \times 9.1^\circ$ of visual angle and equalized for mean luminance using Photoshop® CS5 (Adobe, San Jose, CA). We did not normalize contrast and spatial frequencies in the pictures as these procedures tend to introduce substantial distortions into processed images. They were presented against a black background. None of the stimulus was shown to the participants before the experiment. The image of each participant's face was removed from the computer disc at the end of the experimental session.

Procedure

Participants were seated comfortably in a dimly lit and sound-attenuated room with a constant viewing distance of 57 cm from the computer screen (Eizo Flex Scan EV-2450, Hokusai, Ishikawa, Japan). After electrode cap placement (ActiCAP, Brain Products, Munich, Germany), the participants used an adjustable chinrest to maintain a stable head position. Presentation software (Version 18.2, Neurobehavioral Systems, Albany, CA) was used for stimuli presentation. Participants completed a simple detection task, regardless of the image presented (self-face, emotional or neutral face), and the participants were asked to push the same response button (Cedrus response pad RB-830, San Pedro, USA) as quickly as possible. After reading the instructions displayed on the screen, participants initiated the experiment by pressing a response button. Each trial started with a blank screen, shown for 1500 ms. Next, a white cross (subtending $0.5^\circ \times 0.5^\circ$ of visual angle) was centrally displayed for 100 ms and then followed by a blank screen lasting either 300, 400, 500 or 600 ms at random. Subsequently, a stimulus was presented for 500 ms, followed by a blank screen for 1000 ms. The number of repetitions for each face category was 72. The order of stimuli presentation was pseudo-randomized, i.e. no

more than two stimuli of the same category were displayed consecutively. A break was planned in the middle of experiment to keep participants from tiring. It lasted 1 min, unless the participant decided to start the second part of the experiment earlier. Participants needed on average 19 min to complete the whole experiment.

EEG recording

The EEG was continuously recorded with 62 Ag–AgCl electrically shielded electrodes mounted on an elastic cap (ActiCAP, Brain Products, Munich, Germany) and positioned according to the extended 10–20 system. Two additional electrodes were placed on the left and right earlobes. The data were amplified using a 64-channel amplifier (BrainAmp MR plus; Brain Products, Germany) and digitized at a 500-Hz sampling rate, using BrainVision Recorder software (Brain Products, Munich, Germany). EEG electrode impedances were kept below 10 k Ω . The EEG signal was recorded against an average of all channels calculated by the amplifier hardware.

Behavioural analysis

Responses within a 100–1000 ms time window after stimulus onset were analysed using SPSS (Version 26, IBM Corporation) and JASP (Wagenmakers et al., 2018) software packages. A Shapiro–Wilk test for normality conducted on the distribution of RTs for each stimulus type (self-face, emotionally positive face, emotionally negative face and neutral face) revealed that the distribution of RTs deviated from normality for two stimulus types. Therefore, a Friedman test was used with type of stimulus (self-face, emotionally positive face, emotionally negative face and neutral face) as a within-subject factor. The results are reported with reference to an α -level equal to 0.05.

To conduct statistical analyses of behavioural (RT) and ERP data in a consistent manner, similar to our analyses of ERP components, the traditional null hypothesis significance testing approach was complemented with Bayesian analysis methods. Bayes factors (BFs) were computed using JASP software (Wagenmakers et al., 2018). A BF₁₀ between 1 and 3 implies anecdotal evidence for the presence of an effect (i.e. anecdotal evidence for H₁). A BF₁₀ between 3 and 10 gives moderate evidence, a BF₁₀ between 10 and 30 indicates strong evidence for the presence of an effect, BF₁₀ between 30 and 100—very strong evidence, and a BF₁₀ higher than 100—extreme evidence for H₁ (Lee and Wagenmakers, 2014).

ERP analysis

Offline analysis of the EEG data was performed using BrainVision Analyzer® software (Version 2.2, Brain Products, Gilching, Germany). EEG data from 62 channels were re-referenced offline to the algebraic average of the signal recorded at the left and right earlobes, notch-filtered at 50 Hz, and band-pass-filtered from 0.01 to 30 Hz using a second-order Butterworth filter. After re-referencing and filtering the signal, ocular artefacts were corrected using Independent Component Analysis—ICA (Bell and Sejnowski, 1995). After the decomposition of each data set into maximally statistically independent components, components representing eye blinks were rejected based on a visual inspection of the component's topography (Jung et al., 2001). Using the reduced component-mixing matrix, the remaining ICA components were multiplied and back-projected to the data,

resulting in a set of ocular-artefact-free EEG data. Subsequently, the EEG signal was segmented into 1700-ms-long epochs, from -200 ms before to 1500 ms after stimulus onset. The next step was a semi-automatic artefact rejection procedure that rejected trials exceeding the following thresholds: the maximum permitted voltage step per sampling point was $50 \mu\text{V}$, the maximum permitted absolute difference between two values in the segment was $200 \mu\text{V}$ and the lowest permitted activity within a 100-ms interval was $0.5 \mu\text{V}$. The mean number of segments that were averaged afterwards for each category of stimuli was as follows: self-face—72.241 (s.d. = 2.430), emotionally positive face—72.414 (s.d. = 1.991), emotionally negative face—71.621 (s.d. = 2.624) and neutral face—72.172 (s.d. = 1.910). The number of epochs used to obtain ERPs did not differ significantly between the types of stimuli. Finally, the epochs were baseline-corrected by subtracting the mean of the pre-stimulus period.

Selection of electrodes for ERP analyses has to be orthogonal to potential differences between experimental conditions (Kriegeskorte et al., 2009). Therefore, this has to be done on the basis of the topographical distribution of brain activity (in the time window corresponding to a given component) averaged across all experimental conditions. Electrodes lying within the maxima identified in such a topographical map should be further analysed. Based on the topographical distribution of activity as well as grand-averaged ERPs, collapsed for all experimental conditions (self-face, emotionally positive face, emotionally negative face and neutral face), the following windows were chosen for analysis of ERP components of interest: 200–500 ms for P3 and 650–900 ms and 900–1150 ms for LPP (Figure 1). Two clusters of electrodes within the region of maximal activity were selected: (1) for P3—PZ, CPZ, CP2 and P2 and (2) for LPP—FCZ, FC2 and C2. The data were pooled for those electrodes. This step is justified by the limited spatial resolution of EEG and high correlation between neighbouring electrodes. The mean values at each time point within the aforementioned time windows were used to assess the amplitudes of our ERP components of

interest. This method is less affected by possible low signal-to-noise ratio than peak measure methods (Luck, 2005).

All statistical analyses were performed using SPSS software (Version 26, IBM Corporation), custom Python scripts (Version 3.5, Python Software Foundation) and JASP software (Wagenmakers et al., 2018). The Shapiro–Wilk normality test was conducted on P3, LPP (650–900 ms) and LPP (900–1150 ms) amplitude distributions. For P3 and LPP (650–900 ms) they did not deviate from normality, thus a one-way repeated-measures ANOVA was performed with category of stimuli (four levels: self-face, emotionally positive face, emotionally negative face and neutral face) as a within-subject factor. For LPP (900–1150 ms) with a non-normal amplitude distribution, a Friedman test was applied analogously. Thus, a one-way repeated-measures ANOVA was performed with category of stimuli (four levels: self-face, emotionally positive face, emotionally negative face and neutral face) as a within-subject factor. All effects with more than one degree of freedom in the numerator were adjusted for violations of sphericity (Greenhouse and Geisser, 1959). Bonferroni correction for multiple comparisons was applied to *post hoc* analyses. All results are reported with α -levels equal to 0.05.

The traditional null hypothesis significance testing approach was complemented with Bayesian analysis methods. To test whether the self-face and other faces were characterized by similar levels of neural activity, BFs were computed using JASP software (Wagenmakers et al., 2018). The main reason for choosing BF was that, unlike classic frequentist statistics, BF evaluates how strongly both alternative and null hypotheses are supported by the data. Specifically, BF is a ratio of the probability (or likelihood) of observing the data given the alternative hypothesis is true to the probability of observing the data given the null hypothesis is true. Thus, in our particular case, BF provides further evidence either in favour of similarities or rather differences in self-face and emotional faces processing. The medium prior scale (Cauchy scale 0.707) was used in all Bayesian tests. The Results section provides interpretations of the BF_{10} according to Lee and Wagenmakers (2014).

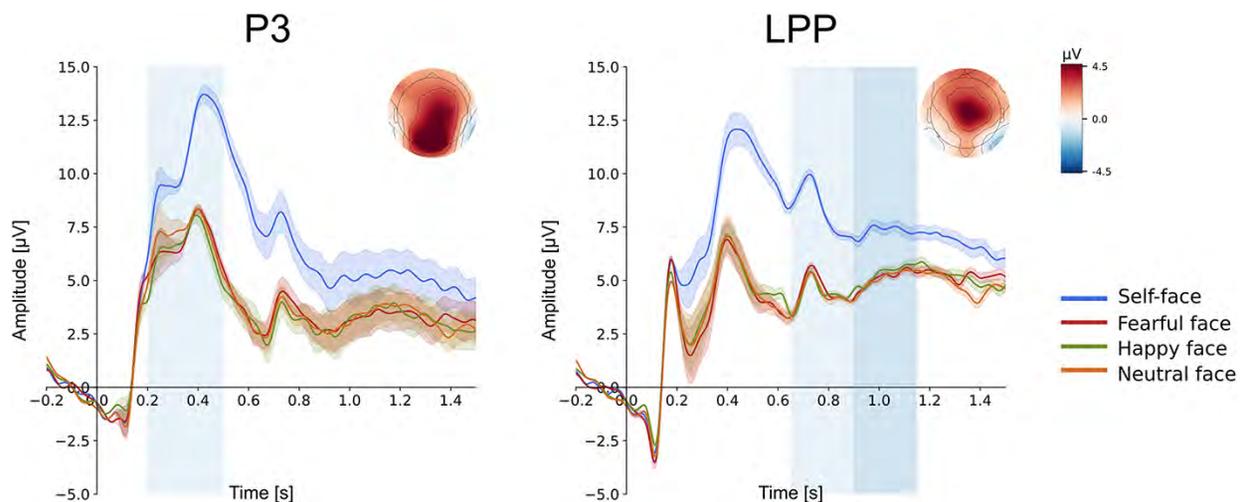


Fig. 1. Grand average ERPs to self-face, fearful, happy and neutral faces. Shaded areas indicate standard deviations (s.d.). Left panel: P3 component for pooled electrodes PZ, CPZ, CP2 and P2 that are within the region of maximal activity in the topographical distribution of brain activity, averaged across all experimental conditions (i.e. four types of faces). Right panel: LPP for pooled electrodes FCZ, FC2 and C2 that are within the region of maximal activity in the topographical distribution of brain activity, averaged across all experimental conditions (i.e. four types of faces). The analysed time windows are marked by light-blue rectangles.

Cluster-based permutation tests

Cluster-based permutation tests were used here as an exploratory analysis procedure, as they efficiently handle the multiple comparisons problem in high-dimensional magnetoencephalographic and EEG data (Sassenhagen and Draschkow, 2019). In contrast to the ERP method, which focuses on data recorded at a single electrode or small set of electrodes in a specific time window, cluster-based permutation tests allow for EEG signal amplitude across all electrodes and all time samples to be compared. We directly compared: self-face vs fearful face processing, self-face vs happy face processing and self-face vs neutral face processing. As clustering in both space and time was used, such an analysis procedure revealed differences in the spatial distributions of activity as a function of time between the tested conditions.

In general, permutation tests are used to test the null hypothesis that the data in the experimental conditions come from the same probability distribution. Getting a significant result means that the null hypothesis can be rejected in favour of the alternative hypothesis, i.e. that the data came from different distributions. Therefore, significant results from permutations tests indicate a significant between-condition difference. The results are reported with reference to an α -level equal to 0.05.

The calculation of a cluster-based permutation test for multiple sensors is performed in the following steps: (i) for every sample, the EEG signal is compared between the two conditions by means of a t-value, (ii) all samples whose t-values are larger than a threshold [in our study we used the threshold-free cluster enhancement (TFCE) method] are selected, (iii) the selected (sensor, time) samples are clustered on the basis of spatial and temporal adjacency, (iv) cluster-level statistics are calculated by taking the sum of the t-values within a cluster and (v) finally, the largest of the cluster-level statistics is taken. The TFCE eliminates the free parameter initial threshold value that determines which points are included in clustering by approximating a continuous integration across possible threshold values with a standard Riemann sum. A significant advantage of TFCE is that, rather than modifying the null hypothesis under testing, it modifies the data under testing while still controlling for multiple comparisons. The statistical test is then done at the level of individual voxels rather than clusters. This allows for the significance of each point to be evaluated independently rather than only as cluster groups.

The non-parametric statistical test is performed by calculating a P-value under the permutation distribution and comparing it with some critical α -level (0.05 in our study). The permutation distribution is obtained by the following procedure: (i) the trials of the two experimental conditions in a single set are collected, (ii) the trials are randomly partitioned into two subsets, (iii) the test statistics is calculated on this random partition and (iv) steps (ii) and (iii) are repeated a large number of times and a histogram of the test statistics is constructed. In practice, it is not possible to calculate the permutation P-value by repeating steps (ii) and (iii) an infinite number of times. Instead, this P-value is approximated by a so-called Monte Carlo estimate. This Monte Carlo estimate is obtained by repeating steps (ii) and (iii) a large number of times and comparing these random test statistics (i.e. draws from the permutation distribution) with the observed test statistics. The Monte Carlo estimate of the permutation P-value is the proportion of random partitions in which the observed test statistics is larger than the value drawn

from the permutation distribution. The accuracy of the Monte Carlo P-value increases with the number of draws from the permutation distribution. In our study, the Monte Carlo P-values were calculated on 1000 random partitions.

Cluster-based permutation tests were conducted using custom-made Python scripts with use of the `mne.stats.spatio_temporal_cluster_1samp_test` function from the MNE Python package.

Representational similarity analysis (RSA)

Representational geometry. A representation of an experimental condition in geometrical space can be defined as a point or cloud of points in a multidimensional space (Kriegeskorte and Kievit, 2013). When analysing EEG signals, these dimensions can be thought as the electrical activity recorded by separate electrodes. The geometrical relation of two neuronal responses can be analysed through the comparison of their locations within this 'electrode' space. That is, a metric such as Euclidean or Mahalanobis distance between these responses in multidimensional space is computed. Euclidean distance was used in the present study to transform the data into geometrical space (Kriegeskorte et al., 2006). Such an approach provides a detailed account of the geometrical structure formed by distinct conditions. It can reflect differences, similarities, and even how much variance in these comparisons is explained by an external factor.

RSA template-based regression. To calculate the Euclidean distance matrices, we first calculated the mean epochs for each condition for each subject. Then, 8×8 Euclidean distance matrices (2 sets of data \times 4 conditions) were computed for each time point, yielding an $851 \times 8 \times 8$ matrix for each participant. To improve the sensitivity of the method, the distance matrix was enlarged by subsampling every condition. More specifically, the trials within each condition were randomly assigned into two pools. This resulted in an 8×8 distance matrix. Next, we applied a least-squares multiple regression model to assess the contribution of the predicted 'template' neuronal codes to the distance matrix:

$$D = \beta_0 + \sum_{n=1}^3 \beta_n \text{template}_n + \varepsilon$$

where D denotes the distance matrix obtained from RSA and ε denotes the error (residual) of the model. β_0 denotes the intercept of the model, which was coded as the identity matrix of the same dimensions as the template matrices. The three template matrices (templates), indexed by the counter (n) were regressed onto the distance matrix to obtain the corresponding regression weights (β_{0-3}). β -values indicate the relative contribution of each template matrix (regressor) to the variance in the distance matrix. The three predicted template matrices were as follows: (i) self-face and emotionally negative face are similar and differ from the two other faces ('self-face + fearful face model'), (ii) self-face and emotionally positive face are similar and differ from the two other faces ('self-face + happy face model') and (iii) self-face differs from all other faces ('self-face model'). These templates were then converted to z-scores to allow for comparisons. The output of our model was a matrix containing β -values for every person, for every time point, for every regressor ($29 \times 851 \times 3$). Furthermore, the resulting β -values

Table 1. Mean median RTs and standard deviation (s.d.) for each type of stimuli ($N = 28$)

	Mean medians	s.d.
Self-face	244.925	26.259
Fearful face	248.754	25.678
Happy face	249.268	25.387
Neutral face	247.652	24.743

Table 2. Mean (M) amplitude (μV) and standard deviation (s.d.) for each analysed component ($N = 29$)

	P3		LPP (650–900 ms)		LPP (900–1150 ms)	
	M	s.d.	M	s.d.	M	s.d.
Self-face	7.771	3.545	16.789	9.129	15.146	9.101
Fearful face	5.103	2.694	9.078	8.033	10.296	8.245
Happy face	4.811	2.262	9.010	8.276	10.938	8.394
Neutral face	5.300	2.220	8.759	7.853	10.399	7.744

were temporally smoothed using a Gaussian window with a width of 32 ms.

Results

Behavioural results

The mean number of responses to all types of stimuli were as follows (mean \pm standard error): self-face (71.500 ± 0.755), fearful face (71.321 ± 0.568), happy face (71.786 ± 0.581) and neutral face (71.679 ± 0.385). Differences between the numbers of responses for different types of faces were non-significant.

The RTs of one participant were found to be greater than 3 s.d. above the mean for each condition, and they were subsequently excluded from further behavioural analysis. A repeated-measures ANOVA, conducted on median RTs in the group of 28 participants, revealed a significant effect of type of stimuli: $F_{3,81} = 3.576$, $P = 0.0174$, $\eta^2 = 0.117$. *Post hoc* comparisons showed that RTs to self-face were significantly shorter than to fearful face ($P = 0.014$, $BF_{10} = 16$). Participants also reacted faster to self-face than to happy face; however, it was only a statistical trend ($P = 0.087$, $BF_{10} = 3$). The other comparisons were non-significant. Descriptive statistics are shown in Table 1.

ERPs results

Mean P3 and LPP amplitudes and s.d. values for correct trials were computed for each type of stimulus, i.e. self-face, fearful face, happy face and neutral face (see Table 2). Grand-average ERPs for all types of faces are presented in Figure 1.

P3 (250–500 ms). One-way repeated-measures ANOVA showed a significant main effect of stimulus type: $F_{3,84} = 31.500$, $P < 0.0001$, $\eta^2 = 0.529$. *Post hoc* analyses revealed that P3 amplitude to the self-face was significantly higher than P3 amplitudes to fearful ($P < 0.0001$, $BF_{10} = 10\,038$), happy ($P < 0.0001$, $BF_{10} = 78\,764$) and neutral faces ($P < 0.0001$, $BF_{10} = 3\,046$). All other comparisons were non-significant.

LPP (650–900 ms). One-way repeated-measures ANOVA revealed a main effect of stimulus type: $F_{3,84} = 50.332$, $P < 0.0001$,

$\eta^2 = 0.643$. In an early time window, LPP amplitude to the self-face was significantly higher than that to fearful ($P < 0.0001$, $BF_{10} = 517\,949$), happy ($P < 0.0001$, $BF_{10} = 2.842 \times 10^6$) and neutral faces ($P < 0.0001$, $BF_{10} = 7.625 \times 10^6$). All other comparisons were non-significant.

LPP (900–1150 ms). A Friedman test yielded a statistically significant difference between LPP amplitudes in the later time window for stimuli type: $\chi^2(3) = 21.290$, $P < 0.001$. For *post hoc* analyses, Wilcoxon signed-rank tests with Bonferroni correction (significance level set at $P < 0.01$) were used. These comparisons revealed significantly higher LPP amplitude to the self-face than to fearful ($Z = -4.141$, $P < 0.0001$, $BF_{10} = 1\,142$), happy ($Z = -3.449$, $P < 0.001$, $BF_{10} = 134$) and neutral ($Z = -4.033$, $P < 0.0001$, $BF_{10} = 1\,748$) faces. All other comparisons were non-significant.

Cluster-based permutation tests

The results of our cluster-based permutation tests indicated that self-face processing differed significantly from the processing of happy, fearful and neutral faces. The differences between those experimental conditions were widely distributed in space and time. They started around 200 ms after the visual stimulus onset and lasted for the subsequent 1200–1400 ms. They were present at numerous electrode sites in the frontal, central and parietal regions. The cluster-based permutation results are presented in Figure 2 for 30 of 62 analysed electrode sites (Figure S2 in the supplementary material shows the results of cluster-based permutation tests for the remaining 32 electrode sites). It is interesting that the broad time window of substantial differences between tested conditions encompasses the time windows in which both ERP components were analysed (250–500 ms and 650–1150 ms for P3 and LPP, respectively). In addition, although P3 and LPP were analysed at electrode sites that were selected on the basis of maximal activity in the topographical distribution maps, similar effects (i.e. higher amplitudes of these ERP components to the self-face than to other faces) were present at virtually all electrodes (Supplementary material S1).

RSA results

Three different models were computed and tested. The first two models were based on the assumption of similarities in the distribution of neural activity associated with the (i) self-face and fearful face ('self-face + fearful face model') and (ii) the self-face and happy face ('self-face + happy face model'). The third model assumed a unique distribution of activity in the case of self-face processing ('self-face model') that did not resemble (i.e. was dissimilar from) distributions of activity for all other faces (happy, fearful and neutral). Thus, similarities in the distribution of neural activity for different experimental conditions implies that the neural code corresponding to the representations of those conditions is similar. Cluster-based one-sample permutation *t*-tests revealed that the model assuming a similarity structure between the distributed patterns of activity elicited by the self-face and the fearful face is a negative predictor of the neuronal activity (cluster time points: 236–932 ms, $P < 0.001$). This suggests that the topographies observed in the self-face and fearful face conditions became more dissimilar as a function of time, starting from an early period of the trial. A similar result was found in the case of the model assuming a similarity structure between the happy and self-face (cluster time points: 394–904 ms, $P < 0.001$). The third model

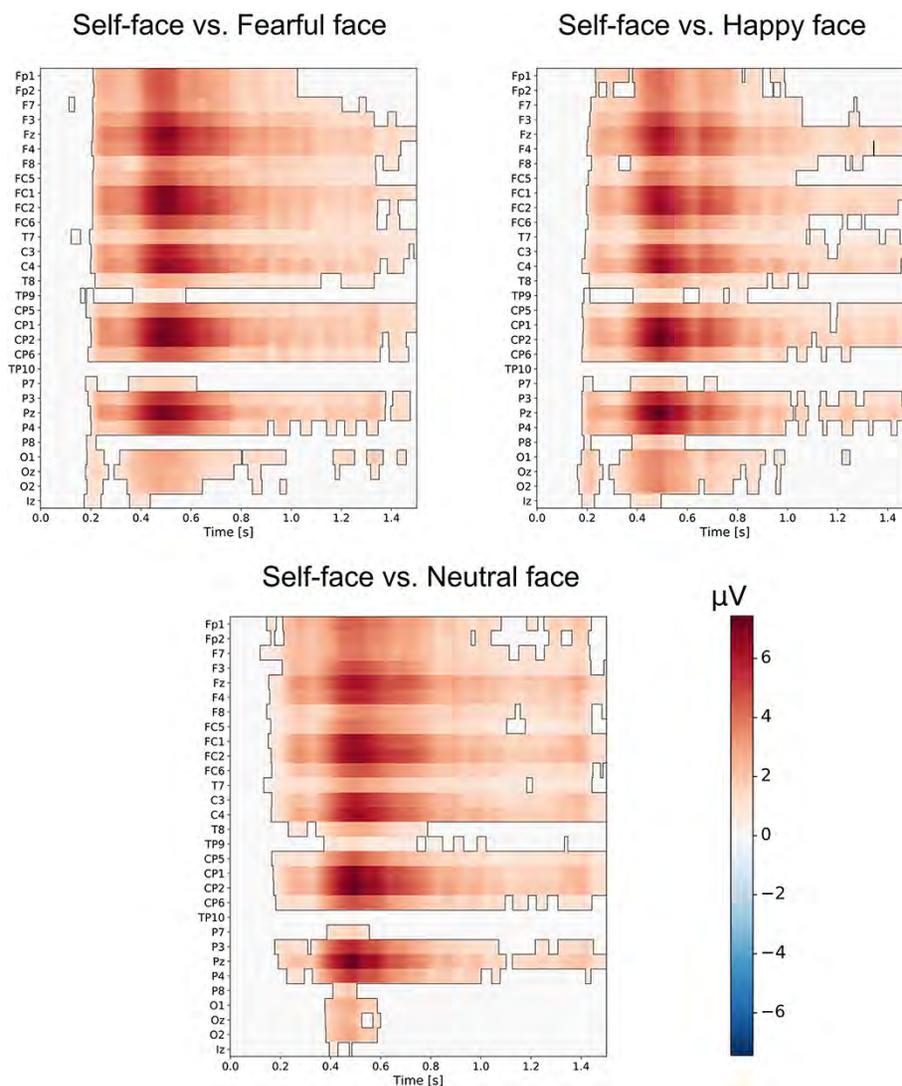


Fig. 2. Results of cluster-based permutations tests. Self-face was compared to fearful and happy face (top left and top right panels, respectively) as well as to neutral face (bottom panel). Statistically significant positive differences between tested experimental conditions are indicated in red ($P < 0.05$). For illustrative purposes, 30 electrodes from the set of 62 are presented. The remaining 32 electrodes are presented in Figure S2 in the supplementary material.

aimed to capture a dissimilarity structure between the self-face and every other experimental condition, as well as a similarity structure between the fearful, happy and neutral faces. A cluster-based permutation test revealed that this model is a positive predictor of the neuronal activity (cluster time points: 202–1154 ms, $P < 0.001$). That is, the spatially distributed pattern of activity elicited in the self-face condition becomes dissimilar to the patterns elicited by other experimental conditions early on in the trials, and this dissimilarity increases as a function of time. This is in line with the first two models and suggests a distinct processing pipeline between the self-face and other experimental conditions. Figure 3 illustrates these results.

Discussion

Despite the fact that recent years have seen a substantial increase of interest in the self in various disciplines, leading to the publication of multiple papers on the topic, many

questions still remained unanswered. One of them refers to the factors that determine the prioritized self-face processing that has been well-documented in numerous studies with different experimental approaches (for a review see: Humphreys and Sui, 2016). As humans are the subject of their own cognition, they are in the unique position of possessing years of detailed visual, tactile, motor and sensory-feedback experiences about themselves, which results in a highly elaborated (not only visual but also multimodal) representation of their own image (Li and Tottenham, 2013). The special saliency of the self-face has been largely agreed upon (Lavie et al., 2003; Gray et al., 2004; Brédart et al., 2006; Pannese and Hirsch, 2011), and converging lines of evidence have confirmed the special status of self-face processing (Bortolon and Raffard, 2018).

The current study aimed at elucidating the plausible role of an emotional relevance factor in the preferential processing of this stimulus by direct comparisons between the self-face and emotional as well as neutral faces. Two types of emotional faces were used: (i) happy faces were introduced, motivated by the

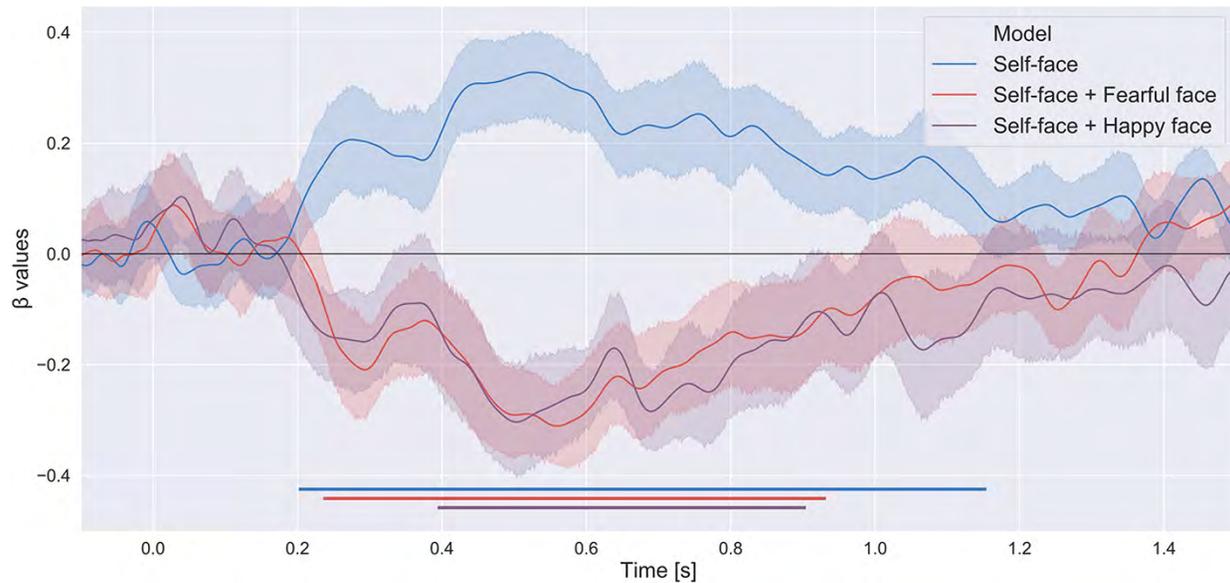


Fig. 3. Results of the representational similarity analysis. Shaded areas indicate confidence intervals (CIs). Three models were tested: (i) self-face and fearful face differ from other faces (happy and neutral); (ii) self-face and happy face differ from other faces (fearful and neutral) and (iii) self-face differs from all other faces (fearful, happy and neutral). Cluster-based one-sample t-tests revealed significant effects for all models (α -levels below 0.05 are indicated by horizontal blue, red and violet lines parallel to the x-axis). However, the first two were negative, not positive, predictors.

self-positive bias (e.g. Greenwald, 1980; Watson et al., 2007) and (ii) fearful faces, because of their high perceptual saliency, i.e. a feature shared with one's own face (Elsherif et al., 2017). EEG data were collected while participants performed a simple detection task. The obtained data were analysed using three methods that complement each other: ERP component amplitude analysis, RSA and cluster-based permutation tests.

The results obtained using those methods clearly indicate that the processing of the self-face substantially differed from the processing of all other (emotional and neutral) faces. Specifically, the process of self-face detection was associated with substantially increased P3 and LPP amplitudes in comparison to emotionally positive, emotionally negative and neutral faces. These effects were both highly significant and robust (mean amplitudes to the self-face were about two times higher than to other faces, either emotional or neutral). In addition, BF_{10} values for comparisons between amplitudes of the analysed ERP components elicited by the self-face and other faces indicated extreme evidence in favour of the alternative hypothesis (all $BF_{10} > 100$). P3 and LPP topography indicated maximal regions of activity in the parietal–central and frontal regions mainly in the right hemisphere. This is in line with fMRI findings indicating the involvement of the right hemisphere (in particular, right fronto-parietal structures) in visual self-recognition (e.g. see Hu et al., 2016 for review; Keenan et al., 2000).

The results of the RSA and cluster-based permutation tests revealed differences between self-face processing and the processing of other types of faces. The RSA that assessed the similarity/dissimilarity of neural activity patterns elicited by the self-face and emotionally positive face, as well as by the self-face and emotionally negative faces, definitely showed that they were highly dissimilar. Thus, RSA findings in the current study strongly point to differences in the spatial distribution of neuronal activity between the processing of self-face and emotional faces. Moreover, cluster-based permutation tests, which were

used to contrast the self-face and emotionally positive faces as well as the self-face and emotionally negative faces, indicated strong and significant differences between the tested conditions. Altogether, the results of different methods used to test similarities between the processing of self-face and happy faces as well as self-face and fearful faces indicate that their neural correlates substantially differed. Importantly, all of these results consistently show strong and significant differences between the self-face and other faces in a prolonged time window: they started 200 ms after the face onset and lasted till ca. 1200 ms.

Our results concerning long-lasting and sustained effects in self-face vs other faces discrimination are in line with the findings of other electrophysiological studies on self-face processing (Alzueta et al., 2019, 2020). Specifically, it has been shown that the self-face is differentiated from other (familiar) faces as early as 200 ms (Alzueta et al., 2019) and such differentiation continues until 1200 ms (Alzueta, 2020). The only difference between the aforementioned studies and the present study is the type of faces that served as a control condition to the self-face (familiar and unfamiliar neutral faces in Alzueta et al.'s studies; unfamiliar emotional faces in our study). Nevertheless, all those findings consistently pointed to sustained activity in the 200–1200 time window associated with the self-face as compared to different types of other faces.

One may argue that effects reported in the present study can be attributed to the extreme familiarity of the self-face in general, as the other types of faces (emotionally positive, emotionally negative and emotionally neutral) were unfamiliar to the participants. Therefore, one cannot rule out the possibility that the familiarity factor had an impact on the pattern of findings reported in the present study. However, the role of high familiarity in the preferential processing of any self-related stimuli has been questioned by numerous studies. Differences between self-face processing and the processing of other familiar faces (e.g. faces of celebrities) were reported in many studies

(e.g. Tacikowski and Nowicka, 2010). Crucially, the role of familiarity seems to be challenged by findings of studies using highly familiar faces, i.e. the faces of close-others, as a control condition to the self-face. In general, they reported differences between the self and the close-other condition in favour of the self (Cygan et al., 2014; Kotlewska and Nowicka, 2015; Kotlewska et al., 2017). In those studies, the close-other was operationalized as the most important person at the time of experimentation and was freely chosen by each participant (e.g. a spouse, a partner and a very close friend). Nevertheless, differences between the self and the close-others' faces were observed on the neural level as indicated by late ERP components (Cygan et al., 2014; Kotlewska and Nowicka, 2015) and steady-state visual evoked potentials (Kotlewska et al., 2017). This seems to indicate that the processing of even highly familiar faces, seen on an everyday basis, differs from the processing of the self-face.

An additional and very strong evidence against the role of the familiarity factor in the prioritized processing of self-related information comes from studies that aimed to investigate newly acquired self-related information (Sui et al., 2012, 2014). It has been demonstrated that after being told to associate three identities (self, friend and stranger) with three arbitrary stimuli (geometrical shapes), participants were faster in a perceptual matching task at recognizing matching pairs of the self-associated shape with a label than for friend- or stranger-related pairings. It is worth noting that in those experimental paradigms levels of familiarity were equalized for the self and other conditions. The findings of this study provided evidence that a brief self-association is sufficient to facilitate processing of previously neutral and new stimuli with no relevance to the self.

However, as noted by Woźniak and Knoblich (2019), in the matching trials of the self-prioritization task, participants are processing not only self-associated arbitrary stimuli but also familiar verbal labels with a pre-experimentally established meaning. Therefore, the self-advantage may be caused by the familiarity of the labels, rather than the self-association of the shapes. Thus, in a recent study, Woźniak and Knoblich (2019) tested whether such self-prioritization can be observed in the absence of any pre-experimentally familiar stimulus related to the self. In their study, participants were asked to associate avatar faces with three identities (self, best friend and stranger). Afterwards, labels (you, friend and stranger) were replaced with unfamiliar abstract symbols that were associated with three identities before the actual experiment started. The results of that study presented the typical pattern of self-prioritization, showing that this effect does not critically depend on the presence of familiar labels and that it can be elicited by initially neutral stimuli. Altogether, those studies suggest that rapid and rather effortless association of initially neutral information with the self leads to subsequent prioritization of this information. All in all, the aforementioned findings undermine the role of the familiarity factor in eliciting the prioritized processing of self-related information.

Our P3 results corroborate the findings of previous studies reporting enhanced P3 to the self-face in comparison to other (either familiar or unfamiliar) faces (Ninomiya et al., 1998; Scott et al., 2005; Sui et al., 2006; Tacikowski and Nowicka, 2010; Cygan et al., 2014; Kotlewska and Nowicka, 2015). Moreover, the P3 results of the current study are in line with the findings of an earlier ERP study with self-face and emotionally negative faces presented as deviant stimuli in an odd-ball procedure (Zhu et al., 2016). In that study, the amplitudes of P3 to the self-face were much higher than that to (unknown) emotional and neutral

faces. In general, such patterns of P3 findings may be viewed in the context of classical models of face recognition (Bruce and Young, 1986; Burton et al., 1990). Although in both studies (Zhu et al., 2016; the present study) the explicit recognition of faces was not required to successfully accomplish the behavioural tasks, it seems reasonable to assume that such recognition happened as it is a rather automatic and very fast process (Wójcik et al., 2018).

Briefly, classical models of face recognition generally posit the following stages of this process: structural encoding, face recognition units (FRUs), person identity nodes (PINs) and semantic information units (SIUs). Structural encoding follows an initial pictorial analysis and consists in capturing the essential structural features of a face. If a face is known, it activates the FRU—a structural representation of a familiar face stored in long-term memory that takes into account the variability of viewpoints, changeable facial features, etc. Next, the corresponding PIN is activated, which is a multimodal representation of the face bearer. When the person is identified, biographical knowledge about them may also be retrieved. This retrieval is thought to entail activation of SIUs. Thus, the essential concept in this framework is the activation of the semantic information related to the identity of the recognized person, i.e. a specific and rich network of facts about the recognized individual (Burton et al., 1990).

ERP studies carried out within the framework of the face recognition models linked the specific stages to specific ERPs components, with P3 reflecting access to PIN and SIU nodes (Paller et al., 2000; Tacikowski et al., 2011). Thus, substantially increased amplitudes of P3 to self-face presentations may result from the extremely rich semantic information referring to the self. Importantly, this type of information is absent in the case of emotional and neutral faces that were unfamiliar to participants, and for that reason no semantic information was available. This may explain both the significant differences between P3 amplitudes to images of the self-face and other faces, as well as the lack of P3 differences between emotional and neutral faces observed in the present study. It is worth noting that in previous studies the amplitude of the P3 component differed as a function of emotional expression (e.g. Cuthbert et al., 2000; Keil et al., 2002; Schupp et al., 2004; Briggs and Martin, 2009; Foti et al., 2009). The lack of these differences in our experiment suggests that the activation of the semantic network related to the self may overwrite earlier saliency effects, i.e. different sources of saliency can interact with each other.

However, other interpretations of P3 findings are also plausible. It is worth noting that the current debate on the functional role of the P3 component refers to many different topics. Among them is the theoretical framework proposing that the P3 reflects the response of the neuromodulatory locus coeruleus–norepinephrine (LC–NE) system to the outcome of internal decision-making processes and the consequent effects of noradrenergic potentiation of information processing (Nieuwenhuis et al., 2005). It was also suggested that P3 may reflect reactivation of well-established stimulus–response (S–R) links (Verleger et al., 2015). Nevertheless, in the context of the present study, P3 interpretations referring to attentional processes seem to be most relevant. Specifically, it has been proposed that the mechanisms boosting the prioritized processing of self-relevant information could be driven by automatic capture of attention and prioritized allocation of attention to the self-related stimuli (review: Humphreys and Sui, 2016; Sui and Rotshtein, 2019). Indeed, several studies found that the self-face automatically captures attention (e.g. Tong and Nakayama, 1999; Brédart et al., 2006;

Alexopoulos et al., 2012; Alzueta et al., 2020), and numerous EEG studies have revealed greater P3 amplitude in response to one's own face (e.g. Tacikowski and Nowicka, 2010; Ninomiya et al., 1998; Sui et al., 2006; review: Knyazev, 2013). As P3 is usually associated with attentional processes (for review see: Polich, 2007), our P3 findings indicate preferential engagement of attentional resources to the self-face. Such an interpretation suggests that the preferential processing of the self as reflected by the P3 may be caused by an early allocation of attentional resources and not a late attentional facilitation caused by a semantic activation (as proposed by the face recognition model). This notion seems to be further supported by the central-parietal topography of the P3 (Polich, 2007). At this point, it should be stressed that reported pattern of findings is not likely to be driven by decision-making processes (there was no specific decision to be made, just a simple detection of a stimulus) or S-R links (regardless of seen face, participants always were pressing the same button).

However, not only P3 but also LPP was significantly increased in the self-face condition. LPP is typically increased by emotional stimuli when compared to neutral visual stimuli (Cuthbert et al., 2000; Hajcak and Nieuwenhuis, 2006; Foti and Hajcak, 2008; Olofsson et al., 2008) and reflects enhanced processing and attention to emotional salient stimuli (Cuthbert et al., 2000). Larger LPP amplitudes are also correlated with increased arousal (Cuthbert et al., 2000). The neural generators of LPP are thought to be the extrastriate visual system and emotion-related structures such as the amygdala (Sabatinelli et al., 2007), and LPP may reflect stronger functional connectivity between the occipital cortex and frontal areas for high arousing emotional relative to low arousing neutral stimuli (Moratti et al., 2011). Our results do not reflect a pattern that was found in previous studies, i.e. the differences in LPP amplitude between emotional and neutral faces. Similar to the P3 component, only the self-face condition was characterized by an increase in LPP amplitude.

One of plausible explanations of this discrepancy may refer to findings of studies showing that the LPP can be modulated by reappraisal, with larger deflections when upregulating an emotional response (Moser et al., 2009) and reduced deflections when downregulating an emotional response (Hajcak and Nieuwenhuis, 2006; Foti and Hajcak, 2008; Schönfelder et al., 2014). One may speculate that the reported pattern of LPP findings (i.e. substantially enhanced LPP for the self-face and decreased LPP to all other faces) may be related to automatically elicited processes such as the augmentation of emotional response in the case of one's own face and its reduction in the case of all other faces (emotional and neutral ones). An alternative interpretation of our findings may refer to the issue raised by Panksepp (1998, 2011): emotional feelings (rather than simple emotions) are intrinsically subjective. Thus, in contrast to (objectively) emotional faces, seeing the self-face may result in an emergence of subjective emotional states associated with increased brain activity. Therefore, the current findings may reflect the distinction between subjectively significant vs subjectively non-significant stimuli, with the self-face being a subjectively significant stimulus and all other faces being subjectively non-significant. This is in line with Bradley's notion (2009) that the key stimulus dimension that modulates LPP amplitude is significance and that indicators of this construct include subjective ratings of arousal, autonomic response and the activation of specific neural circuits.

Importantly, the lack of P3 and LPP differences between emotional and neutral stimuli may be related not only to the early or late engagement of attentional resources. An additional

and complementary explanation of that effect may refer to the degree or the magnitude of the saliency features of the presented faces and, therefore, to the specificity of these saliency effects. Both analysed ERP components are modulated by the saliency of stimuli (P3—Teixiero et al., 2010; LPP—Martin et al., 2020) and thus, substantially increased P3 and LPP amplitudes to the self-face may reflect the extreme saliency of this stimulus, in line with other studies (Humphreys and Sui, 2015). However, P3 and LPP response to potentially salient emotional faces did not differ from P3 and LPP response to neutral faces. One may speculate that images of emotional faces were not viewed as salient when compared with the self-face image. Thus, it might be speculated that different sources of salience interact with each other (self-related vs not self-related) and exerted a differential influence on the analysed ERP components. Such a hypothesis seems to find some support in the results obtained by Marti et al. (Marti et al., 2015; Marti and Dehaene, 2017). These authors showed that the processing of two different tasks or target stimuli can take place in parallel at early stages of information processing. However, at later stages the representations of each task/stimuli compete with each other for attentional resources where the winner is subject to an all-or-none activation. Although such an early parallel processing and late selection model seems to explain our P3 and LPP findings, it is worth noting that this model was tested using different experimental paradigms than those applied in the present study. In Marti et al.'s experiments, the stimuli were displayed in a rapid serial stream and their saliency was determined in a top-down fashion. It is yet to be determined whether events within a broader time scale can be subject to a similar processing architecture and how intrinsic saliency modifies these operations.

To further investigate the winner-takes-all late selection process, as revealed by the absence of P3 and LPP differences between emotional and neutral faces, additional analyses were conducted on the recorded data (the results of those analyses are included in the [Supplementary Data](#)). The analysis of an early face-selective ERP component (N170) revealed that both types of emotional faces differed from neutral faces. A linear discriminant analysis (LDA) conducted for a discriminant function between the happy, fearful and neutral faces clearly showed that these conditions were differentiated in an early time window. When the self-face condition was added, the decoder revealed that the category information persisted throughout the whole trial window (see [Figure S4](#) and [Figure S5](#) in the [Supplementary Data](#)). This is in line with the ERP analyses showing that the happy, fearful and neutral conditions are mainly differentiated early on, whereas the self-face condition adds a component that allows the information to persist in a late time window. These results suggest that the emotional saliency differentiated, in fact, the experimental conditions but only in an early time window. It seems that this saliency effect was overwritten by the special status of the self-face on later stages on information processing.

All in all, the findings of our different analytical approaches provide converging evidence of the self-face being processed preferentially at later stages of information processing. Moreover, this effect is unlikely to be caused by the low-level features of the images as the happy, fearful and neutral faces are differentiated by the participants in an early time window.

The aforementioned differences between the self-face vs other faces processing, observed at the neural level, were accompanied by differences at the behavioural level. Specifically, RTs to the self-face were shorter than RTs to fearful and happy faces.

This is in line with numerous studies showing that detection of one's own face is much faster than detection of other faces (for review see: [Bortolon and Raffard, 2018](#)).

The main limitation of our study is the lack of an additional control condition that presents a mixture of the extreme familiarity and emotional load factors, as it is the case for the self, e.g. a best friend's or partner's face. Inclusion of such faces would enable us to test whether effects similar to those observed for the self-face can be observed for faces that are not only as familiar as the self-face but also subjectively very significant. Such an approach would reveal whether the differences between the self-face and other (emotional and neutral) faces were self-specific only or whether other highly familiar and highly significant faces were processed similar to the self-face. Future studies that expand the current paradigm by inclusion of such an additional condition may contribute to the discussion on the issue of whether the self is a higher-order function or a fundamental function of the brain ([Northoff, 2016](#)) and may provide some additional arguments in favour of one of the opposite views.

In conclusion, our ERP results as well as the results of RSA and cluster-based permutation tests consistently showed differences between the self-face and other (emotionally negative, emotionally positive and emotionally neutral) faces. These findings strongly suggest that self-face processing does not resemble the processing of emotional faces, thus implying that self-referential processing is truly reflective of self. They also seem to point to the crucial role of subjective significance as a leading factor in the prioritized self-face processing. Direct comparisons of the self-face vs emotional faces processing may be applied in the further experimental pursuit of the mechanisms underlying self-referential processing and may shed new light on the operations that are necessary for self-awareness. In this context, the winner-takes-all characteristic of the self-preference effects and its temporal resolution seems to be particularly relevant.

Authors' contributions

A.N. developed the idea of the study. A.Ż., M.M.N., M.J.W. and A.N. contributed to the study design. A.Ż., M.M.N. and A.N. collected the data. A.Ż. and M.M.N. conducted the P3 and LPP analyses. A.Ż. performed statistical analyses of behavioural data and ERPs. M.M.N. and M.J.W. conducted permutation tests and RSA. M.N. created the figures. A.Ż., M.M.N, M.J.W. and A.N. wrote parts of the paper. All the authors revised the manuscript and approved the final version.

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Conflict of interest

The authors declare no conflict of interest.

Supplementary data

Supplementary data are available at SCAN online.

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Supplementary Material

Figure S1. Grand-average ERPs at all 62 electrodes

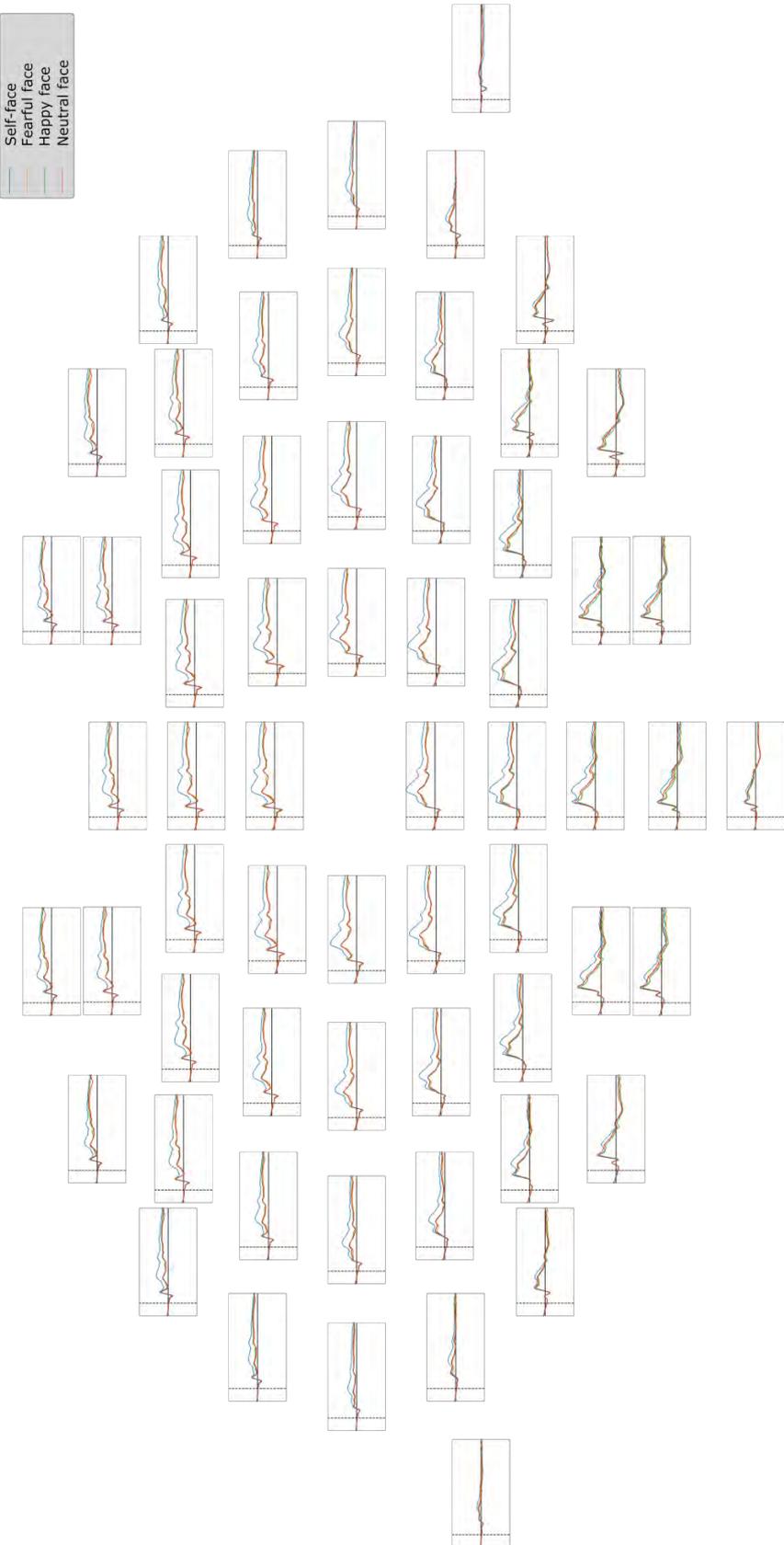


Figure S2. Results of permutation tests for 32 electrodes that were not presented in Fig. 2.

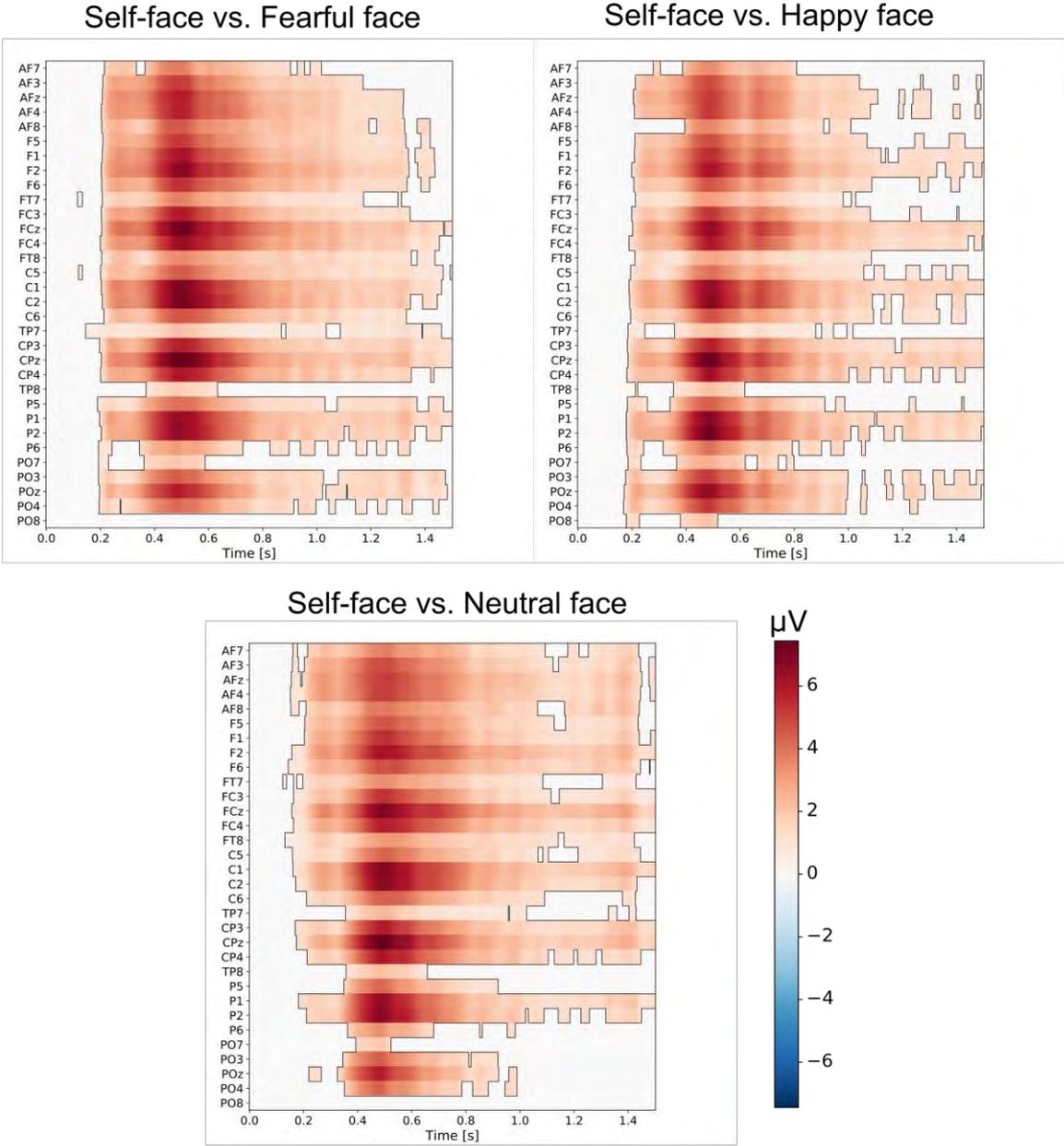
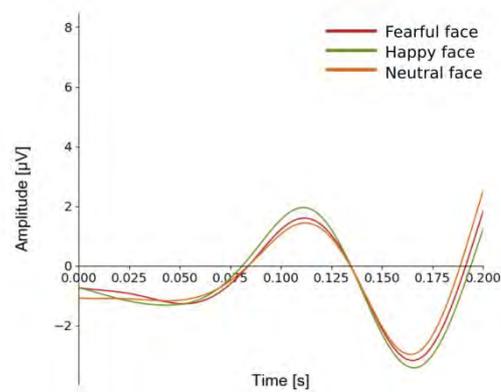


Figure S3. Grand-average ERPs associated with processing of happy, fearful, and neutral faces in the N170 time-window for pooled P6, P8, and PO8 electrodes.



The N170 is related to early stages of face encoding (Eimer, 2000). Some studies have showed that N170 is influenced by emotional expressions displayed by facial stimuli (e.g. Blau et al., 2007). In the present study, the amplitude of this ERP component was measured and analyzed as a peak-to-peak against the preceding P100 (Cygan et al. 2004). Planned comparisons revealed that N170 associated with the processing of emotional faces significantly differed from N170 to neutral faces (happy vs. neutral: $t(28) = -2.772$, $P = .006$; fearful vs. face: $t(28) = -2.437$, $P = .011$)

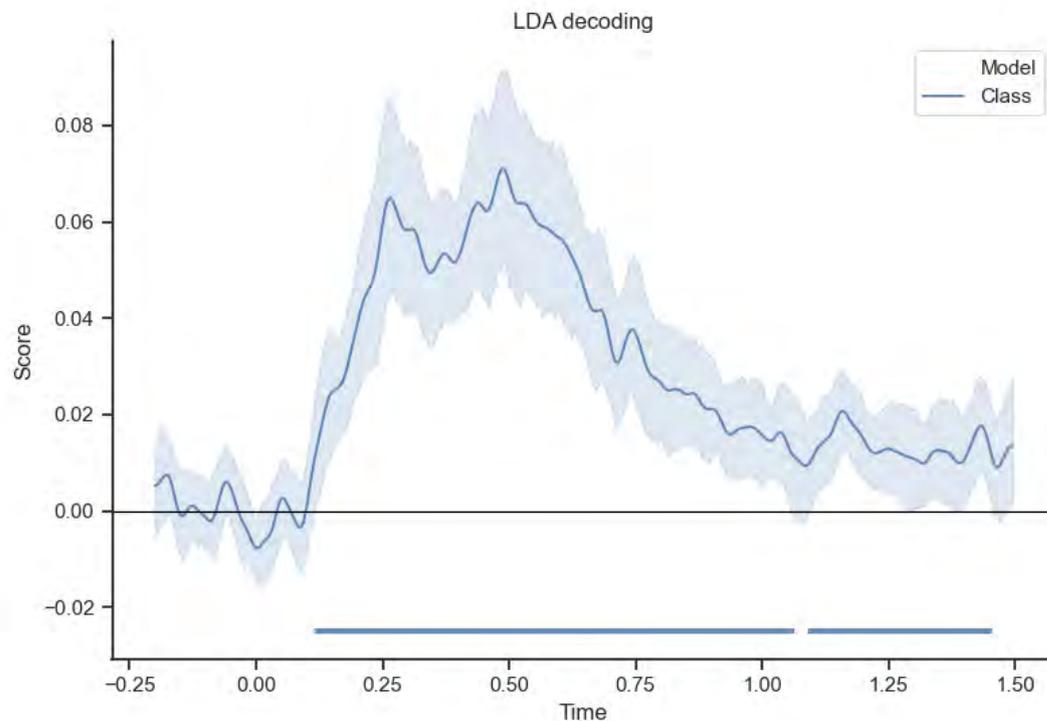
Blau, V. C., Maurer, U., Tottenham, N., & McCandliss, B. D. (2007) The face-specific N170 component is modulated by emotional facial expression. *Behavioral Brain Function*, 3, 7.

doi:10.1186/1744-9081-3-7

Cygan, H. B., Tacikowski, P., Ostaszewski, P., Chojnicka, I., & Nowicka, A. (2014) Neural correlates of own name and own face detection in autism spectrum disorder. *PLoS One*, 9 (1), e86020. <https://doi.org/10.1371/journal.pone.0086020>

Eimer, M. (2000) Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clinical Neurophysiology* 111: 694–705. doi: 10.1016/S1388-2457(99)00285-0

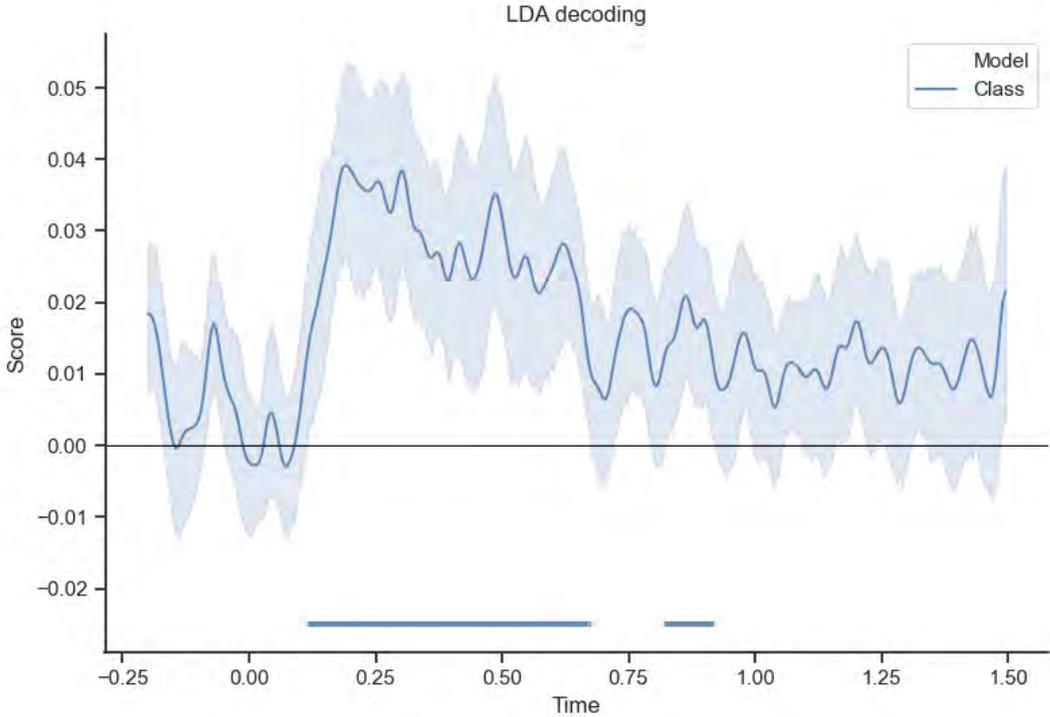
Figure S4. LDA decoding of self-, happy, fearful, and neutral faces (colored bars indicate significant effects).



To assess whether other experimental conditions (neutral, happy and fearful expressions) were differentiated and to investigate the possible time dynamics of these effects, we used a linear discriminant analysis (LDA). LDA is a statistical method used to find a linear combination of features (in our case amplitude values registered at each sensor) that optimally separates two or more classes of objects (i.e. experimental conditions). In neuroscience, the results of such an analysis are often interpreted as the amount of information about a specific category affiliation that is encoded in the system. This is related to the fact that the operations necessary for a linear readout (weighted sum and threshold operations) can be implemented in single unit in a biologically plausible fashion and indicate the presence of explicitly accessible information (e.g. Hung et al., 2005).

Hung, C. P., Kreiman, G., Poggio, T., & DiCarlo, J. J. (2005). Fast readout of object identity from macaque inferior temporal cortex. *Science*, 310(5749), 863-866.

Figure S5. LDA decoding of happy, fearful, and neutral faces (colored bars indicate significant effects).



Publication 2

Żochowska, A., Jakuszyk, P., Nowicka, M. M., & Nowicka, A. (2022). Are covered faces eye-catching for us? The impact of masks on attentional processing of self and other faces during the COVID-19 pandemic. *Cortex*, *149*, 173-187.

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OŚWIADCZENIE

Jako pierwszy autor artykułu:

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oświadczam, że mój wkład w powstanie tej publikacji polegał na:

- współdziałale w opracowaniu koncepcji badania
- opracowaniu procedury eksperymentalnej
- napisaniu skryptu w PRESENTATION do prezentacji bodźców wzrokowych z zaprogramowaniem losowej sekwencji bodźców oraz z wysyłaniem znaczników bodźców do oprogramowania rejestrującego sygnał EEG
- przygotowaniu indywidualnego zestawu bodźców wzrokowych dla każdej osoby badanej (wyrównanie parametrów zdjęć twarzy własnej i twarzy osoby bliskiej, „nałożenie” – w programie graficznym – zdjęcia maseczki chirurgicznej)
- rekrutacji osób badanych
- przeprowadzeniu wszystkich badań z rejestracją EEG
- analizie danych elektrofizjologicznych z wykorzystaniem metody potencjałów wywołanych
- analizie statystycznej amplitud potencjałów wywołanych
- analizie źródeł zarejestrowanego sygnału EEG
- analizie statystycznej danych behawioralnych
- współdziałale w interpretacji i dyskusji wyników
- opisanu procedury i metody
- zaplanowaniu prezentacji graficznej uzyskanych wyników
- przygotowaniu części rycin do publikacji

- współdziałanie w pisaniu wstępnej wersji manuskryptu
- korekcie i uzupełnianiu finalnej wersji manuskryptu

Anna Zochowska

Warszawa, 31.08.2023

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Jako współautor pracy:

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oświadczam, że mój wkład w powstanie tej publikacji polegał na pomocy w przygotowaniu bodźców wzrokowych (twarzy zakrytych maseczką chirurgiczną), współudziale w rekrutacji osób badanych, pomocy technicznej w przeprowadzeniu badań z rejestracją EEG (przygotowanie czepka z elektrodami, zaś po założeniu czepka na głowę osoby badanej – aplikacja żelu w celu zmniejszenia oporności, mycie elektrod) oraz współudziale w analizie źródeł zarejestrowanego sygnału EEG.

Wyrażam zgodę na przedłożenie w/w pracy przez mgr Annę Żochowską jako części rozprawy doktorskiej w formie spójnego tematycznie cyklu artykułów opublikowanych w czasopismach naukowych. Oświadczam, że w/w publikacja lub wyniki wchodzące w jej skład nie będą stanowić części mojej rozprawy doktorskiej.

Paweł Jakuszyk

Warszawa, 31.08.2023

Dr Maria Nowicka

OŚWIADCZENIE

Jako współautorka pracy:

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oświadczam, że mój wkład w powstanie tej publikacji polegał na pomocy technicznej w przeprowadzeniu części badań z rejestracją EEG, opracowaniu skryptu do analizy dyskryminacji liniowej oraz przygotowaniu części rycin do publikacji.

Jednocześnie wyrażam zgodę na przedłożenie w/w pracy przez mgr Annę Żochowską jako części rozprawy doktorskiej w formie spójnego tematycznie cyklu artykułów opublikowanych w czasopiśmie naukowych.

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Warszawa, 31.08.2023

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OŚWIADCZENIE

Jako promotor mgr Anny Żochowskiej oraz współautor pracy:

Żochowska A, Jakuszyk P, Nowicka MM, Nowicka A. (2022). Are covered faces eye-catching for us? The impact of masks on attentional processing of self and other faces during the COVID-19 pandemic. Cortex, 149, 173–187.

oświadczam, że publikacja ta powstała w ramach realizacji kierowanego przeze mnie grantu OPUS (nr 2018/31/B/HS6/00461). Moja rola w powstaniu tej publikacji polegała na ustaleniu koncepcji badania i zaprojektowaniu schematu badania, sprawowaniu nadzoru merytorycznego, konsultowaniu analizy danych, dyskusji i interpretacji uzyskanych wyników oraz współudziale w pisaniu manuskryptu.





Research Report

Are covered faces eye-catching for us? The impact of masks on attentional processing of self and other faces during the COVID-19 pandemic



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ABSTRACT

During the COVID-19 pandemic, we have been confronted with faces covered by surgical-like masks. This raises a question about how our brains process this kind of visual information. Thus, the aims of the current study were twofold: (1) to investigate the role of attention in the processing of different types of faces with masks, and (2) to test whether such partial information about faces is treated similarly to fully visible faces. Participants were tasked with the simple detection of self-, close-other's, and unknown faces with and without a mask; this task relies on attentional processes. Event-related potential (ERP) findings revealed a similar impact of surgical-like masks for all faces: the amplitudes of early (P100) and late (P300, LPP) attention-related components were higher for faces with masks than for fully visible faces. Amplitudes of N170 were similar for covered and fully visible faces, and sources of brain activity were located in the fusiform gyri in both cases. Linear Discriminant Analysis (LDA) revealed that irrespective of whether the algorithm was trained to discriminate three types of faces either with or without masks, it was able to effectively discriminate faces that were not presented in the training phase.

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Recently the world has encountered a unique challenge. The COVID-19 pandemic has brought many changes to our daily lives. Since March 2019, we have been instructed to take special

measures of precaution in order to avoid virus transmission. One of the newly introduced safety requirements was covering our mouths and noses with surgical-like protective masks. For a

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whole year now, in most of our public social encounters we have been observing other people's faces through a thin veil of their masks. This begs the question of whether such a dramatic change to our public face perception has any effect on the cognitive aspects of face processing.

So far there have been few studies related to that topic. Carragher and Hancock (2020) found that surgical face masks have a significant negative effect on face matching performance in a task where participants had to decide if two faces presented simultaneously belong to the same person. Interestingly, this detrimental effect did not differ, whether one or both faces in each pair were masked and was similar in size for both familiar and unfamiliar faces. Furthermore, Calbi et al. (2021) presented participants with different facial expressions (angry, happy, neutral) covered by a surgical-like mask or by a scarf. The participants were then asked to recognize expressed emotions and estimate the degree to which they would maintain social distancing measures for each face. The results revealed that even though the given faces were covered, participants were still able to correctly decode the facial expressions of emotions. When assessing social distancing measures it was found that females choices were driven mostly by the emotional valence of the stimuli. Men's choices, on the other hand, were influenced by the type of face cover.

Noyes et al. (2021) have likewise explored the effects of masks and sunglasses (i.e., an occlusion that individuals tend to have more experience with) on familiar and unfamiliar face matching, as well as emotion categorization. In comparison to fully visible faces, reduced accuracy in all three tasks was observed for partially visible faces. There was little difference in performance for masked faces and faces in sunglasses. Additionally, matching accuracy was lower for the mask condition than for unconcealed faces, regardless of face familiarity. This finding was later confirmed by Estudillo et al. (2021), who reported that compared to a full-view condition, matching performance decreased when a face mask was superimposed on (1) one face and (2) both faces in a pair. Additionally, participants with better performance in the full-view condition, generally showed a stronger negative impact of mask presence. Freud et al. (2020), in turn, used a modified version of the Cambridge Face Memory Test (CFMT), where faces were presented in both masked and unmasked conditions. Their results showed that face masks lead to a robust decrease in face processing abilities. Similar changes were found whether masks were included during the study or the test phases of the experiment. Moreover, the study demonstrated that masked faces subjected to inversion showed a reduction of inversion effect compared to unmasked faces. This result suggests that processing of masked faces relies less heavily on holistic processing and focuses more on the available features (e.g., eyes, eyebrows). The effect of a substantial decrease in performance for masked faces in a modified version of CMFT was recently replicated by Stajduhar et al. (2021).

The mentioned studies show that wearing surgical-like masks is indeed a factor that influences our ability to process faces. Face masks disrupt configural/holistic face processing and promote instead a local, feature-based processing. Importantly, similar effects were found for both familiar and unfamiliar masked faces (Carragher & Hancock, 2020; Noyes et al., 2021). However, the impact of a mask on

one's own face processing has not been yet investigated. Thus, a question arises regarding whether covering such a highly familiar face with a surgical-like mask can alter its processing similarly to other faces, familiar or not. One's own face differs from other faces not only in respect of its extreme familiarity but also in respect of its saliency (Apps et al., 2015; Brédart et al., 2006; Gray et al., 2004; Lavie et al., 2003; Pannese & Hirsch, 2011; Wójcik et al., 2018, 2019; Żochowska et al., 2021). The self-face, in comparison to other faces, benefits from a stronger and more robust mental representation (Bortolon & Raffard, 2018; Tong & Nakayama, 1999). Moreover, in contrast to other faces, self-face processing draws upon both configural and featural information (Keyes & Brady, 2010; Keyes et al., 2012). It is a unique piece of self-referential information, that is strongly linked to the physical self-identity (Estudillo, 2017; McNeill, 1998) and consistently shows a processing advantage over both unfamiliar and familiar faces (e.g., Sui et al., 2006; Tacikowski & Nowicka, 2010; Żochowska et al., 2021). One account for this self-face preference refers to attentional mechanisms as one's own face captures, holds, and biases attention in various conditions and on different levels of processing (for review see: Humphreys & Sui, 2016; Sui & Rotshtein, 2019).

Therefore, in the current study, we were interested in whether such attention-related effects can also appear for the self-face when covered by a surgical-like mask. Attention is a multifaceted construct composed of distinct stages (Petersen & Posner, 2012). First, people reflexively orient to relevant signals/stimuli because they initially capture attention (Posner, 1980). Second, salient stimuli trigger a state of general alertness that helps to sustain attention (Sturm et al., 1999). Lastly, executive control involves shifting attention to target stimuli and executing a behavioral response (Duncan, 1980). Thus, the first aim of our study was to investigate the early and late stages of attentional mechanisms involved in the processing of one's own face and other faces (familiar, unfamiliar) when covered by surgical-like masks.

We used the event-related potentials (ERPs) method to achieve this goal. Analyses were focused on early and late ERP components: (i) P100 (a positive ERP component with occipitoparietal distribution, occurring approximately 100 msec after a visual stimulus onset) linked to early, stimulus-driven attentional processes (Luck et al., 2000; Magnun, 1995; Mangun & Hillyard, 1991); (ii) P300 (a positive ERP component with a centro-parietal distribution and latency of about 300 msec) viewed as a neural marker of subsequent attention allocation (Asanowicz et al., 2020; Polich, 2007); (iii) Late Positive Potential (LPP) (a positive, sustained ERP component starting around 500 msec after stimulus onset with a wide frontal-central topography) reflecting a non-specific (i.e., global) temporary increase in attention that serves to facilitate the processing of salient stimuli (Brown et al., 2012). We hypothesized that the amplitudes of attention-related ERP components (P100, P300, LPP) would be enhanced for the self-face when covered by a surgical-like mask, thus indicating preferential capture and allocation of attention.

Besides the issue of attentional processes associated with the processing of mask-covered faces (self versus others), we attempted to address a question that is more general in nature and refers to the issue of whether partial information about

faces is treated similarly to fully visible faces by the human brain. Therefore, the second aim of the current study was to examine similarities/dissimilarities between fully visible faces and mask-covered faces using the following methods: ERPs (with focus on the N170 component), source analysis (LORETA), and linear discriminant analysis (LDA).

The N170 (a negative ERP component with parietal-occipital topography and a latency of 170 msec) reflects the operation of a neural mechanism tuned not only to detect human faces but also to discriminate faces from other object categories (Bentin et al., 1996; Eimer et al., 2000; Rossion et al., 2000; Schweinberger & Neumann, 2015). It is typically regarded as a marker of the structural encoding of faces (for a review see: Eimer, 2011). Based on the functional role of this ERP component, a similar N170 response to faces with and without surgical-like masks would indicate that the upper part of a face and a fully visible face are not differentiated at a categorical level.

Moreover, we investigated whether in the case of visual stimulation with images of faces covered by surgical-like masks, sources of recorded brain activity were located in the fusiform gyrus. Common sources identified within the fusiform gyrus both for (uncovered) faces and upper parts of faces would indicate that such a partial information about faces was sufficient to activate highly specialized brain region, strongly involved in face-processing in general (Haxby et al., 2000, 2001; Rossion, 2014).

LDA, in turn, served as a tool to assess: (i) the capability of the algorithm that was taught to discriminate different types of unmasked faces (based on neural activity associated with processing of such faces) to discriminate faces with surgical-like masks; (ii) the capability of the algorithm that was taught to discriminate different types of faces with surgical-like mask to discriminate faces without masks. Both approaches seem to be ecologically valid: the first one in the case of the self-face and the close-other's face, the second one in the case of unfamiliar faces. This notion may be justified in the following way. Before the beginning of the COVID-19 pandemic, people had a long-time experience with viewing their own and their close-other's faces without any mask. Therefore, representations of both faces are rich and highly elaborated which enables configural processing of robust represented faces (Keyes, 2012). However, it is not the case for unfamiliar faces. In addition, during the COVID-19 pandemic due to the requirements to cover faces with masks, only partial information about facial features is available. We were curious to find out whether an algorithm trained to discriminate full images of highly familiar faces from unfamiliar faces will be able to discriminate different types of faces on the basis of partial information available for processing. Faces of unknown people, in turn, are nowadays viewed with surgical-like masks and sometimes it is necessary to recognize/identify people with masked faces. For this reason, we were also interested whether an algorithm trained on masked faces would discriminate unmasked faces.

Previous studies explored the impact of masks on the processing of celebrity and unknown faces (Carragher & Hancock, 2020; Noyes et al., 2021). In the current study, we decided to use a close-other's face (freely chosen by each participant) instead of famous faces. The face of a close-other is frequently encountered on an everyday basis and its level of

familiarity is as high as in the case of the self-face. Thus, the self-face, a close-other's face, and unfamiliar faces were presented to participants in two conditions: with and without surgical-like masks.

Participants were tasked with the simple detection of presented faces. This task is considered to be a purely attentional task as it depends mostly on attentional resources involved in the processing of incoming visual information (Bortolon & Raffard, 2018). It is worth noting that an advantage of such tasks is that the observed patterns of findings are not likely to be driven by decision making processes (there was no specific decision to be made, just a simple detection of a stimulus) or by stimulus-response (S-R) links (regardless of the observed face participants always pressed the same button).

1. Materials and methods

1.1. Participants

Thirty-two participants (16 females, 16 males) between the ages of 21 and 34 ($M = 27.6$; $SD = 3.1$) took part in the study. Twenty-nine participants were right-handed and 3 left-handed as verified with the Edinburgh Handedness Inventory (Oldfield, 1971). Only participants with normal or corrected-to-normal vision with the use of contacts and with no distinctive facial marks were recruited. This restriction was introduced to ensure the uniformity of visual stimuli standards, as the photograph of each participant was matched with photographs from the Chicago Face Database – CFD (Ma et al., 2015). Images included in this database present faces without glasses and without any visible marks. All participants reported no history of mental or neurological diseases.

The required sample size was estimated using the MorePower software (Campbell & Thompson, 2002). Estimation was conducted for the main factor of 'stimuli' (faces with surgical-like mask, faces without surgical-like mask) in two-way repeated measures ANOVA with factors of 'stimuli' and 'type of face' (self, close-other's, unknown): estimated effect size $\eta^2 = .25$, $\alpha = .05$, $\beta = .90$. The result indicates a required sample size of 30 participants.

As the study was conducted during the COVID-19 pandemic, it should be noted that all our participants (PhD students and employees at the Nencki Institute) as well as the researchers involved in this study were tested for the SARS-CoV-2 virus on a weekly basis. This was done within the SONAR-II project (www.nencki.edu.pl), which aimed at evaluating the effectiveness of the pooled testing strategy, developed at the Nencki Institute (in cooperation with the University of Warsaw). The SONAR-II covers the asymptomatic population of people who do not meet the criteria for SARS-CoV-2 testing, according to epidemiological regulations, but who may come into contact with infected people. All our participants and researchers had negative results at the time of the study.

1.2. Ethics statement

All experimental procedures were approved by the Human Ethics Committee of the Institute of Applied Psychology at

Jagiellonian University. The work described here has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. Written informed consent was obtained from each participant prior to the study and all participants received financial compensation for their participation.

1.3. Stimuli

Similarly to our previous studies on the topic of self-face processing, the set of stimuli in the current study was individually tailored for each participant (Tacikowski et al., 2011; Tacikowski & Nowicka, 2010; Wójcik et al., 2018, 2019; Bola et al., 2021; Żochowska et al., 2021). It consisted of single face images of three types: the self-face, a close-other's face, and an unknown face. Each type of face was presented with and without a surgical-like mask. An image of a surgical-like mask (Freud et al., 2020) was fitted to each face using Photoshop® CS5 (Adobe, San Jose, CA), fully covering the nose and the mouth. Examples of faces with and without a surgical-like mask are shown in Fig. 1.

Self-face photographs were taken prior to the experiment. Participants were asked to maintain a neutral facial expression when photographed. The close-other was freely chosen by each participant to avoid the situation in which a predefined close-other would not really be a significant person in the participant's opinion. This approach was applied in our earlier studies (Cygan et al., 2014; Kotlewska et al., 2017; Kotlewska and Nowicka, 2015, 2016). The only restriction was that the close-other had to be of the same gender as the participant. A photograph of the close-other's face (with a neutral facial expression) was delivered by the participant. Finally, photographs of unknown faces were taken from the Chicago Face Database - CFD (Ma et al., 2015). The gender of faces from the CFD was matched to each participant's gender to control for the between-category variability. Different images of unknown faces were used in individual sets of stimuli in order to avoid the plausible influence of one selected image on the pattern of brain activity.

Pictures of faces within each stimuli set (i.e., images of the self-face, a close-other's face, a selected CFD face) were extracted from the background, grey-scaled, cropped to include only the facial features (i.e., the face oval without hair), and resized to subtend $6.7^\circ \times 9.1^\circ$ of visual angle using Photoshop® CS5 (Adobe, San Jose, CA). The mean luminance of all visual stimuli was equalized using the SHINE toolbox

(Willenbockel et al., 2010), and faces were presented against a black background. None of the stimuli were shown to the participants before the experiment.

1.4. Procedure

Participants were seated comfortably in a dimly lit and sound-attenuated room with a constant viewing distance of 57 cm from the computer screen (DELL Alienware AW2521HFL, Round Rock, Texas, USA). After electrode cap placement (ActiCAP, Brain Products, Munich, Germany), the participants used an adjustable chinrest to maintain a stable head position. Presentation software (Version 18.2, Neurobehavioral Systems, Albany, CA) was used for stimuli presentation. Participants completed a simple detection task: regardless of the image presented (self-face with/without surgical-like mask, close-other's face with/without surgical-like mask, unknown face with/without surgical-like mask), they were asked to push the same response button (Cedrus response pad RB-830, San Pedro, USA) as quickly as possible. After reading the instructions displayed on the screen, participants initiated the experiment by pressing a response button. Each trial started with a blank screen, shown for 1500 msec. Next, a white cross (subtending $.5^\circ \times .5^\circ$ of visual angle) was centrally displayed for 100 msec and then followed by a blank screen lasting either 100, 200, 300, 400, 500 or 600 msec at random. Subsequently, a stimulus was presented for 500 msec, followed by a blank screen for 1000 msec. The number of repetitions for each stimulus type was 50. The order of stimuli presentation was pseudo-randomized, i.e., no more than two stimuli of the same category were displayed consecutively. A break was planned in the middle of experiment to enable participants to rest. It lasted 1 min, unless the participant decided to start the second part of the experiment earlier. Participants needed on average 20 min to complete the whole task.

1.5. EEG recording

The EEG was continuously recorded with 62 Ag–AgCl electrically shielded electrodes mounted on an elastic cap (ActiCAP, Brain Products, Munich, Germany) and positioned according to the extended 10–20 system. Two additional electrodes were placed on the left and right earlobes. The data were amplified using a 64-channel amplifier (BrainAmp MR plus; Brain Products, Germany) and digitized at a 500-Hz sampling rate, using



Fig. 1 – Examples of faces with and without a surgical-like mask. They present two co-authors of this study.

BrainVision Recorder software (Brain Products, Munich, Germany). EEG electrode impedances were kept below 10 k Ω .

1.6. Behavioural analysis

Responses within a 100–1000 msec time-window after stimulus onset were analysed using SPSS (Version 26, IBM Corporation) and reported results were cross-checked with Statcheck (<http://statcheck.io/index.php>). A two-way repeated measure ANOVA was performed with type of stimulus (faces with mask, faces without mask) and type of face (self, close-other's, unknown) as within-subject factors. The results are reported with reference to an alpha level equal to .05.

1.7. ERP analysis

Off-line analysis of the EEG data was performed using custom scripts written in Python (Version 3.5, Python Software Foundation). EEG data from 62 channels were re-referenced off-line to the algebraic average of the signal recorded at the left and right earlobes, notch filtered at 50 Hz, and band-pass-filtered from .01 to 30 Hz using a 2nd order Butterworth filter. After re-referencing and filtering the signal, ocular artefacts were corrected using Independent Component Analysis – ICA (Bell & Sejnowski, 1995). After the decomposition of each data set into maximally statistically independent components, components representing eye blinks were rejected based on a visual inspection of the component's topography (Jung et al., 2001). Using the reduced component-mixing matrix, the remaining ICA components were multiplied and back-projected to the data, resulting in a set of ocular-artefact-free EEG data. Subsequently, the EEG signal was segmented into 1,700-msec-long epochs, from –200 msec before to 1,500 msec after stimulus onset. The next step was a semi-automatic artefact rejection procedure that rejected trials exceeding the following threshold: the maximum permitted absolute difference between two values in a segment was 100 μ V. Two data sets had to be excluded from the sample during preprocessing based on too few trials remaining after artefacts rejection (the threshold for exclusion was set at less than 50% of trials). The mean number of segments that were averaged afterwards for each category of stimuli was as follows: self-face – 37.5 ($SD = 12.0$), self-face with a surgical-like mask – 37.6 ($SD = 11.8$), close-other's face – 37.6 ($SD = 13.5$), close-other's face with a surgical-like mask – 38.1 ($SD = 12.2$), unknown face – 37.4 ($SD = 12.1$), and unknown face with a surgical-like mask – 37.4 ($SD = 12.1$). The number of epochs used to obtain ERPs did not differ significantly between the types of stimuli. Finally, the epochs were baseline-corrected by subtracting the mean of the pre-stimulus period.

The selection of electrodes for ERP analyses has to be orthogonal to potential differences between experimental conditions (Kriegeskorte & Kievit, 2013). Therefore, this must be done on the basis of the topographical distribution of brain activity (in the time window corresponding to a given component) averaged across all experimental conditions. Based on the topographical distribution of activity as well as grand-averaged ERPs, collapsed for all conditions (self-face, close-other's face, unknown face, self-face with a surgical-like

mask, close-other's face with a surgical-like mask, unknown face with a surgical-like mask), the following windows were chosen for analysis of ERPs components of interest: 90–150 msec for P100, 140–200 msec for N170, 300–600 msec for P300, and 400–900 msec for LPP (Fig. 2). Six clusters of electrodes within the region of maximal changes of activity were selected: for P100 – left: O1 and PO3, right – O2 and PO4; for N170 – left: P7 and PO7, right: P8 and PO8; for P300 – CPz, CP1, CP2, and Pz; for LPP – Fz, F2, F4, and FCz. The data were pooled within each cluster. This step is justified by the limited spatial resolution of EEG and high correlation between neighbouring electrodes. Peak amplitudes were analyzed for P100 and N170, while the mean values at each time point within the aforementioned time window were used to assess P300 and LPP mean amplitude. In the case of ERP components that do not have a clear peak, this method of assessing amplitudes is less affected by possible low signal-to-noise ratio than peak measure methods (Luck, 2005).

All statistical analyses were performed using the JASP software and custom Python scripts (Version 3.5, Python Software Foundation). Reported results were cross-checked with Statcheck (<http://statcheck.io/index.php>). For P100 and N170 amplitudes, a three-way ANOVAs were performed with hemisphere (left, right), type of stimulus (faces with masks, faces without masks), and type of face (self, close-other's, unknown) as within-subject factors. For P300 amplitudes, two-way repeated measure ANOVAs were performed with type of stimulus (faces with masks, faces without masks) and type of face (self, close-other's, unknown) as within-subject factors. In the case of early ERP components (P100, N170), analyses of amplitudes were complemented by analogous ANOVAs run on latencies.

All effects with more than one degree of freedom in the numerator were adjusted for violations of sphericity (Greenhouse & Geisser, 1959). Bonferroni correction for multiple comparisons was applied to post-hoc analyses. All results are reported with alpha levels equal to .05.

1.8. Linear discriminant analysis (LDA)

Briefly, LDA identifies a linear combination of features that optimally separates two or more classes of data (Balakrishnama & Ganapathiraju, 1998; Fisher, 1936). In the current study, the scikit-learn Python library was used (<https://scikit-learn.org/stable/>). LDA was applied to assess whether: (1) an algorithm that differentiated faces with surgical-like masks was efficient in discriminating faces without such masks; (2) an algorithm that differentiated faces without surgical-like masks was efficient in discriminating faces with such masks and to investigate the possible time dynamics of these effects.

1.9. Source analysis

Brain Electrical Source Analysis (BESA v.7.1, MEGIS Software GmbH, Munich, Germany) was used to model sources of the ERPs signal. Source estimations were performed on the averaged data of 30 participants. This analysis was focused solely on differentiating two conditions of faces: covered and uncovered by surgical-like masks. Type of face (self, close-other's,

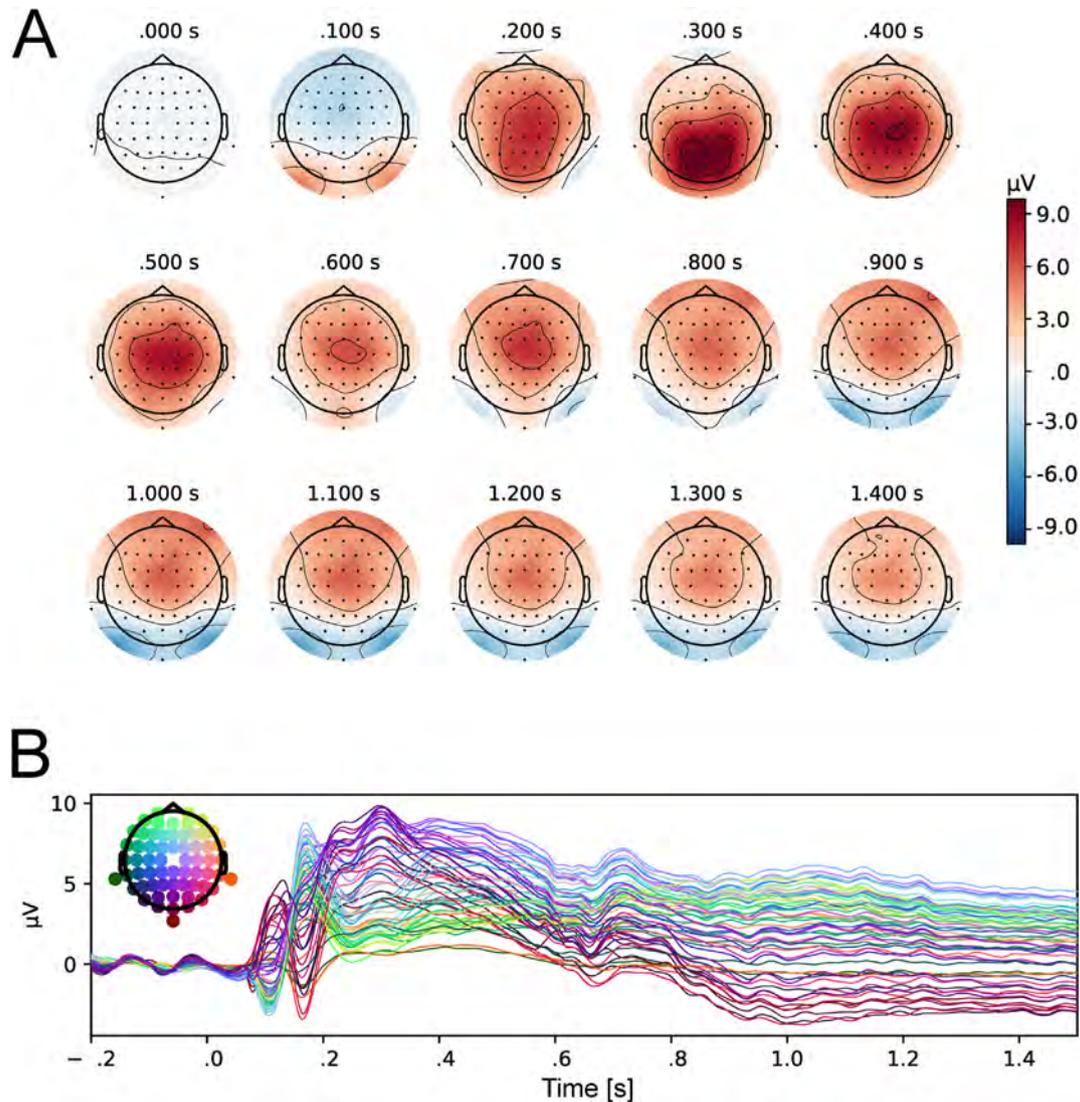


Fig. 2 – Maps of topographical distribution of activity collapsed for all experimental conditions: self-face, close-other's face, unknown face, self-face with a surgical-like mask, close-other's face with a surgical-like mask, unknown face with a surgical-like mask (A) and butterfly plot presenting grand-average ERPs for collapsed all experimental conditions, at all 62 active electrodes (B).

unknown) trials with respect to different types of stimuli (with mask, without mask) were averaged together in order to create the two desired conditions. Source estimation was performed on 200 ms-long post stimulus segments that were extracted from the averaged data. Two clear components were observed in this time interval, one positive peaking at a latency of 110 msec (P100) and a negative component peaking at approximately 170 msec (N170). Only the peak-to-peak interval of those components (110–160 msec for faces without surgical-like masks, 110–168 msec for faces with surgical-like masks) was taken into the model fit, as it resembles the actual neural postsynaptic activity (Key et al., 2005). Two methods of source analysis were applied: discrete sources analysis (dipole fitting) and a distributed source imaging method CLARA (Classical LORETA Analysis Recursively Applied).

1.9.1. Discrete source analysis

Regional sources composed of three single dipoles at one location oriented orthogonal to each other were used to model three-dimensional ERP current waveforms originating from within a certain brain region (Paul-Jordanov et al., 2016). Two regional sources were fit bilaterally and symmetrically in the area of the fusiform gyrus, which is recognized as one of the most crucial structures in face processing (Burns et al., 2019; Haxby et al., 2000, 2001; Rossion, 2014). Symmetry constraints with respect to location were applied to the pair of lateral sources in order to limit the number of parameters being estimated (Schweinberger et al., 2002). No other constraints with respect to localization were applied. The fit interval assigned to the source model was dominated by a single PCA component. The final source solution required a residual

variance of less than 10% (Berg & Scherg, 1994; Tarkka & Mnatsakanian, 2003), i.e., a goodness of fit over 90%.

1.9.2. Distributed source analysis

Compared to the abovementioned method, distributed source analysis estimates the underlying generators without any prior assumptions on the number and locations of the sources. The distributed sources volume-based method CLARA (Beniczky et al., 2016) is an iterative application of the Low Resolution Electromagnetic Tomography (LORETA) algorithm (Pascual-Marqui et al., 1994), with an implicit reduction of the source space in each iteration (Paul-Jordanov et al., 2016). CLARA was used to automatically identify sources and verify the hypothesis regarding the fusiform gyrus activation and differences between processing of faces with and without surgical-like masks.

2. Results

2.1. Behavioral results

The RTs of one participant were found to be beyond 3 SD above the mean for each condition, and were thus excluded from further analysis. The mean RTs to all types of stimuli were as follows (mean \pm standard deviation): self-face (289.9 \pm 57.5), self-face with surgical-like mask (297.3 \pm 64.0), close-other's face (294.3 \pm 65.6), close-other's face with surgical-like mask (291.7 \pm 62.8), unknown face (293.1 \pm 70.8), and unknown face with surgical-like mask (292.9 \pm 62.2).

A repeated-measures ANOVA conducted on mean RTs revealed a significant 2-way interaction: face \times surgical-like mask ($F(2, 60) = 3.450$; $P = .038$; $\eta^2 = .103$). Both the main effect of face and main effect of surgical-like mask were found to be non-significant. Post-hoc tests of the face \times surgical-like mask interaction showed that RTs to self-face without surgical-like mask were significantly shorter than to self-face with surgical-like mask ($P = .014$). The other comparisons were non-significant.

2.2. ERPs results

2.2.1. P100

Statistical analysis of P100 amplitudes showed the significant main effects of 'hemisphere' ($F(1, 29) = 6.438$, $P = .017$, $\eta^2 = .068$) and 'type of stimulus' ($F(1, 29) = 9.798$, $P = .004$, $\eta^2 = .039$). These statistical findings indicated that (1) P100 amplitudes recorded at the occipito-parietal region in the left hemisphere were higher than P100 amplitudes recorded at the occipito-parietal region in the right hemisphere (6.79 \pm 3.71 μ V vs. 5.74 \pm 3.48 μ V), and (2) P100 amplitudes were substantially enhanced for all types of faces covered by surgical-like masks in comparison to faces without masks (6.66 \pm 3.73 μ V vs. 5.89 \pm 3.46 μ V).

Analysis of P100 latencies showed the significant main effect of 'type of stimulus' ($F(1, 29) = 15.589$, $P < .001$, $\eta^2 = .108$). P100 latency for faces with surgical-like masks were longer than for faces without masks (129.2 \pm 17.7 ms vs. 122.7 \pm 17.6 ms). All other effects and interactions were non-significant. Fig. 3 (panel A) illustrates the P100 results.

2.2.2. N170

Grand-average ERPs in the N170 ms time window are presented in Fig. 3 (panel B). Analysis of N170 amplitudes showed that none of the factors nor their interaction reached the level of statistical significance. Analysis of N170 latencies, in turn, showed the significant main effect of 'type of stimulus' ($F(1, 29) = 43.115$, $P < .001$, $\eta^2 = .217$). Analogously to P100 results, N170 latency for faces with surgical-like masks was longer than for faces without masks (171.3 \pm 9.6 ms vs. 163.9 \pm 11.3 ms).

2.2.3. P300

Analysis of P300 amplitudes revealed the significant main effects of 'type of stimulus' ($F(1, 29) = 12.704$, $P = .001$, $\eta^2 = .073$) and 'type of face' ($F(2, 58) = 25.085$, $P < .001$, $\eta^2 = .284$). The interaction of these two factors was non-significant. The significance of the 'type of stimulus' factor indicated that P300 amplitudes associated with the processing of faces with surgical-like masks were substantially increased in comparison to faces without such masks (8.63 \pm 4.54 μ V vs. 7.45 \pm 4.34 μ V).

In addition, post hoc tests on the 'type of face' factor showed that: (1) P300 amplitude to the self-face was higher than to the close-other's face (9.55 \pm 4.76 μ V vs. 7.84 \pm 4.39 μ V, $P < .001$); (2) P300 amplitude to the self-face was higher than to the unknown face (9.55 \pm 4.76 μ V vs. 6.73 \pm 4.27 μ V, $P < .001$); (3) P300 amplitude to the close-other's face was higher than to unknown face (7.84 \pm 4.39 μ V vs. 6.73 \pm 4.27 μ V, $P = .023$). Fig. 4 (panel A) presents grand-average ERPs at pooled CPz, CP1, CP2, and Pz electrodes.

2.2.4. LPP

Analysis of LPP amplitudes showed the significant main effects of 'type of stimulus' ($F(1, 29) = 4.550$, $P = .041$, $\eta^2 = .026$) and 'type of face' ($F(2, 29) = 16.285$, $P < .001$, $\eta^2 = .228$). The interaction of these two factors was non-significant. The significance of the 'type of stimulus' factor indicated that LPP amplitudes associated with processing of faces with surgical-like masks were higher than to faces without such masks (6.02 \pm 3.44 μ V vs. 5.33 \pm 3.12 μ V).

Post hoc tests on the 'type of face' factor showed enhanced LPP amplitude to the self-face in comparison to the close-other's face (7.04 \pm 3.76 μ V vs. 5.45 \pm 3.11 μ V, $P = .002$) and unknown face (7.04 \pm 3.76 μ V vs. 4.54 \pm 2.97 μ V, $P < .001$). Fig. 4 (panel B) presents grand-average ERPs at pooled Fz, F2, F4, and FCz electrodes.

2.3. LDA results

The algorithm trained to discriminate self-face, close-other's face and unknown faces that were without surgical-like masks was efficient in discriminating those types of faces when covered by surgical-like masks. LDA revealed a significant cluster in the 95–770 msec time-window ($P < .001$). In addition, the algorithm trained to discriminate all types of faces with surgical-like masks (self-face versus. close-other's face versus. unknown face) was also able to properly discriminate those types of faces without surgical-like masks. LDA revealed a significant cluster in the 95–1000 msec time-window ($P < .001$). All LDA results are presented in Fig. 5.

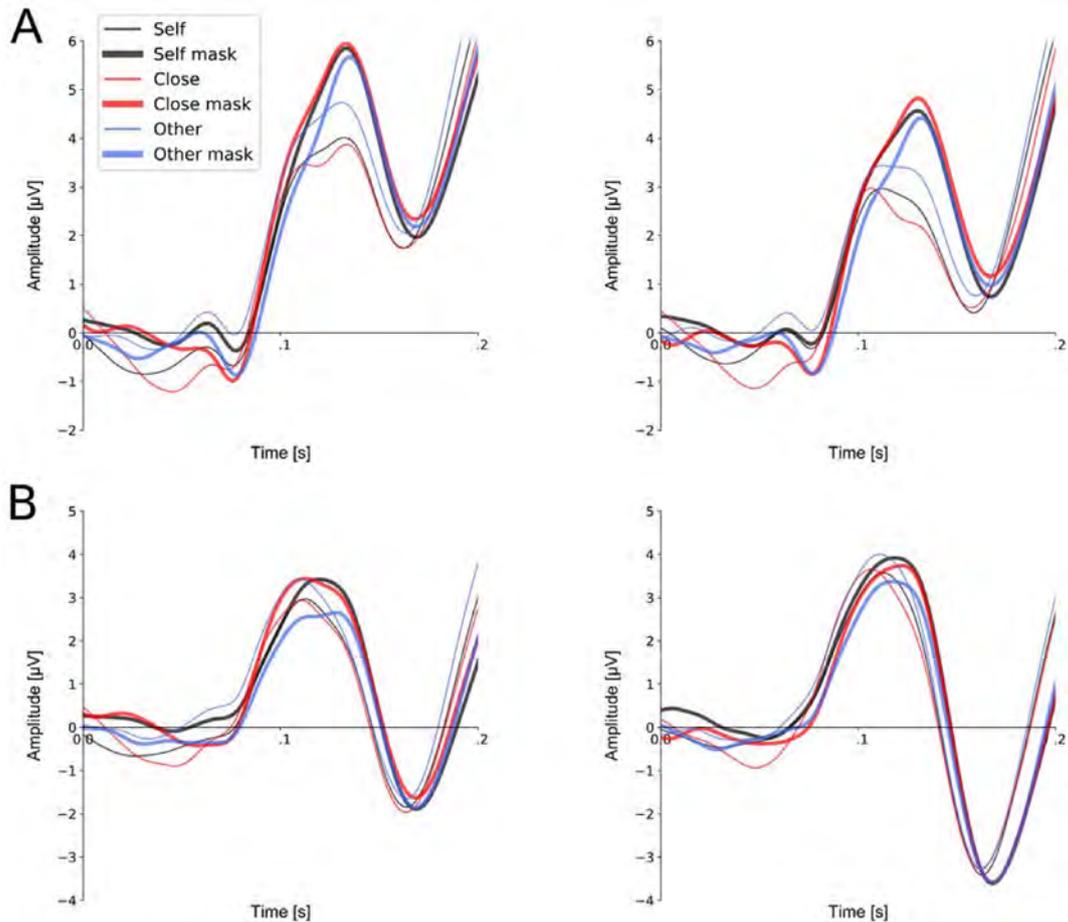


Fig. 3 – Grand average ERPs in the P100 time-window and in N170 time-window to self-face, close-other's face, unknown face with and without a surgical-like mask. Upper panel A: P100 component for pooled electrodes O2 and PO4 within the right occipital-parietal region and pooled electrodes O1 and PO3 within the left occipital-parietal region. Lower panel B: N170 component for pooled electrodes P8 and PO8 within the right parietal region. Peak amplitude of this component was analyzed in the 140–200 msec time-window.

2.4. Source analysis results

The discrete source analysis revealed ERP dipole sources fitted at symmetrical bilateral locations (x , y , z Talairach coordinates): ($x = -35.4$, $y = -54.0$, $z = -5.3$), ($x = 35.4$, $y = -54.0$, $z = -5.3$) for faces without surgical-like masks and ($x = -34.2$, $y = -56.6$, $z = -7.3$) ($x = 34.2$, $y = -56.6$, $z = -7.3$) for faces with surgical-like masks. The applied solutions explained 97.41% and 97.83% of the models, respectively. Moreover, the obtained coordinates did indeed correspond to the localization of the fusiform gyrus within ± 2 mm cube range identified by the Tailarach Client 2.4.2 (Lancaster et al., 2000).

The distributed sources analysis with use of CLARA estimated the strongest activity at bilateral locations in response to (1) faces without surgical-like masks: ($x = -24.5$, $y = -65.9$, $z = -11.3$), ($x = 31.5$, $y = -51.9$, $z = -4.3$) and (2) faces with surgical-like masks: ($x = -17.5$, $y = -72.9$, $z = -11.3$) ($x = 31.5$, $y = -51.9$, $z = -4.3$), identified by the Tailarach Client as the fusiform gyrus within ± 5 mm cube range around the peak of a given activation. Fig. 6 presents all of the aforementioned results.

3. Discussion

Faces are one of the most critical classes of visual stimuli from which people may acquire social information. Faces inform us about the age, sex, mood, direction of gaze, person's identity etc. The ability to extract this kind of information within a fraction of a second plays a crucial role in our social lives. Humans have developed specialized cognitive and neural mechanisms dedicated specifically to the processing of faces (Kanwisher & Yovel, 2006). Due to safety requirements during the COVID-19 pandemic, we have been confronted on an everyday basis with faces covered by surgical-like masks. This raises several questions about how our brains process this kind of visual, socially-relevant information.

Previous behavioral studies showed that surgical-like masks exert a strong influence on our ability to efficiently match (Carragher & Hancock, 2020; Estudillo et al., 2021; Noyes et al., 2021) and remember faces (Freud et al., 2020; Stajduhar et al., 2021). In the current study, we investigated the impact of surgical-like masks on the neural underpinnings

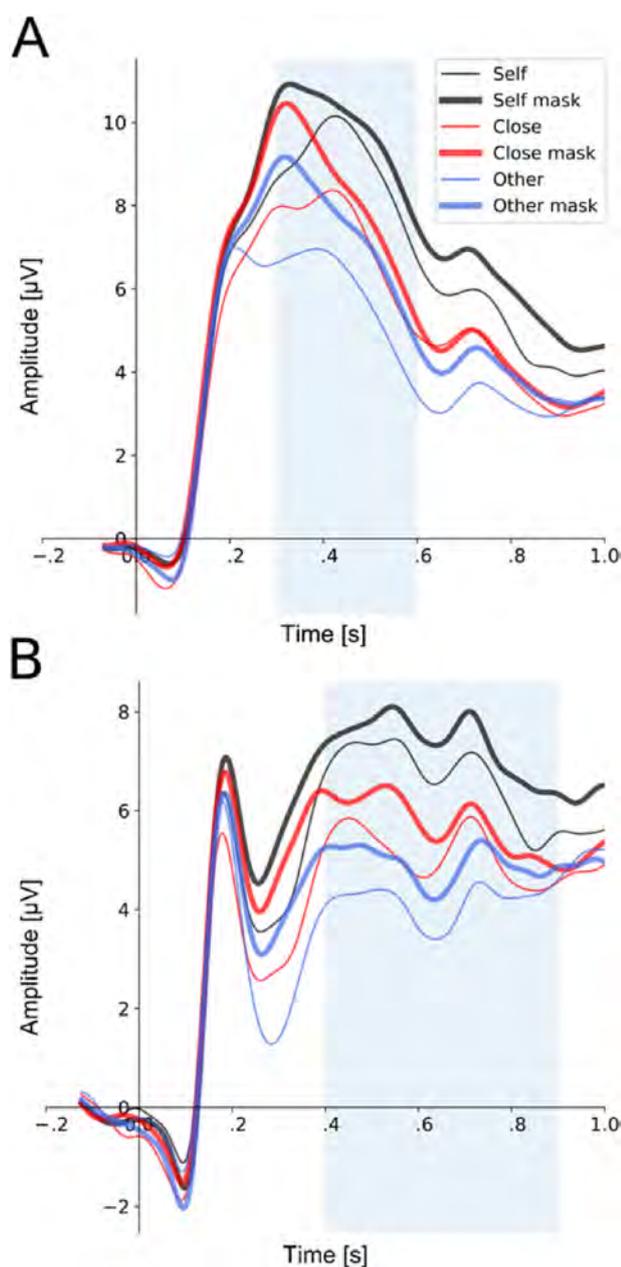


Fig. 4 – Late ERP components P300 (Panel A) and LPP (Panel B). Left panel A: P300 component for pooled electrodes Pz, CPz, CP2, and P2 that were within the region of maximal activity in the topographical distribution of brain activity, averaged across all experimental conditions. Right panel B: LPP for pooled electrodes FCz, Fz, FC2, and C2 that were within the region of maximal activity in the topographical distribution of brain activity, averaged across all experimental conditions. The analyzed time windows are marked by light-blue rectangles.

of personally familiar (self, close-other's) and unfamiliar face processing. We found that the effects related to surgical-like masks were similar for all faces. This is in line with previous studies investigating the effects of masks on familiar and unfamiliar face processing (Carragher & Hancock, 2020; Noyes et al., 2021). Our results showed that early and late attention-

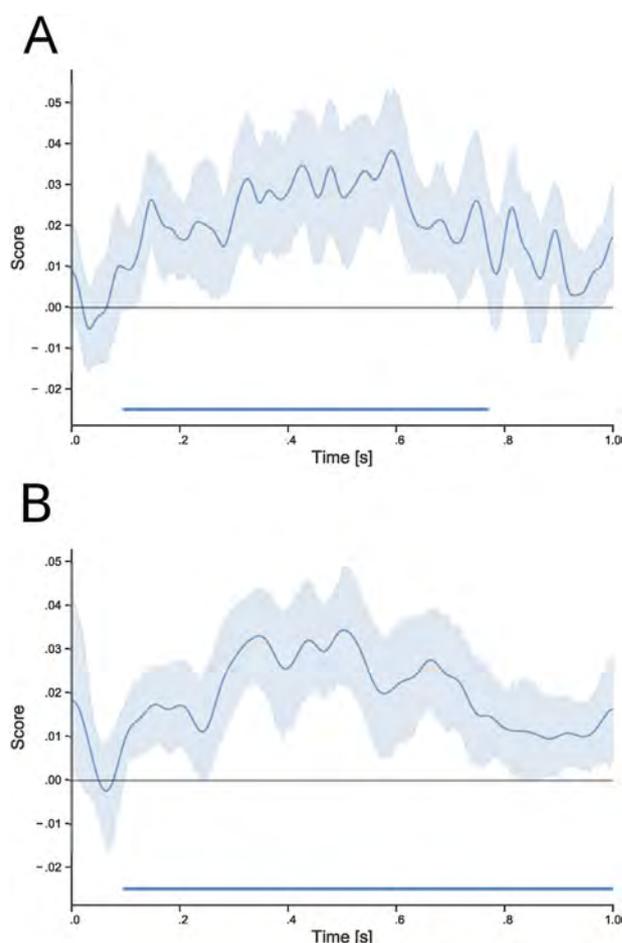


Fig. 5 – Results of Linear Discriminant Analysis. Panel A: LDA algorithm trained to discriminate uncovered self-face, close-other's face, and unknown faces properly discriminates those faces covered by surgical-like masks. Panel B: LDA algorithm trained to discriminate three types of faces covered by surgical-like masks discriminates uncovered self-, close-other's, and unknown faces. Horizontal blue bars indicate statistically significant effects. Shaded areas indicate 95% CI.

related ERP components were substantially increased not only for the self-face with a surgical-like mask but also for other masked faces (close-other's, unfamiliar) in comparison to faces without masks. In addition, the prioritized processing of one's own face was observed, irrespective of presence or absence of a surgical-like mask, as revealed by enhanced P300 and LPP. The detailed results were as follows.

Within the initial one hundred milliseconds after the onset of visual stimuli, amplitudes and latencies of an early ERP component (P100) were higher for all covered versus. uncovered faces. In the consecutive one hundred milliseconds time-window, longer latencies of N170 were observed for all faces with surgical-like masks. Thereafter, P300 amplitudes differentiated both faces with and without masks and different types of faces (self-, close-other's, unfamiliar). P300 was enhanced for all faces covered with surgical-like masks and P300 was higher to the self-face than to the close-other's and unfamiliar faces (the latter two also differed). However, the lack of significant 'type of

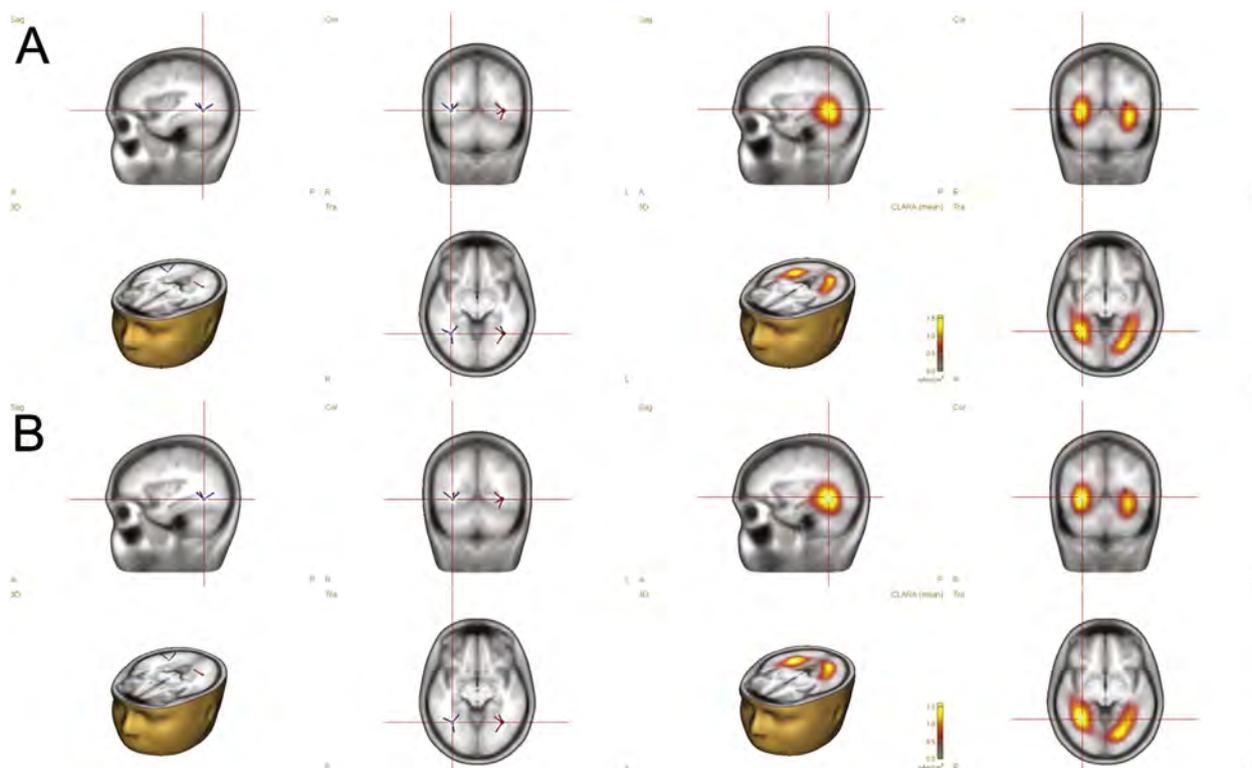


Fig. 6 – Source analysis of ERP responses. Distributed source imaging with CLARA (Classical LORETA Analysis Recursively Applied) points to the fusiform gyrus as the most active generator of the signal elicited by presentation of masked faces (Panel A) and unmasked faces (Panel B). Two dipoles fitted within the fusiform gyrus explains almost 98% of the data.

stimulus' x 'type of face' interaction indicated that P300 effects reflecting the influence of surgical-like masks were similar for personally relevant and personally irrelevant faces. Finally, the late ERP component (LPP) showed an analogous to P300 pattern of findings (i.e., increased LPP amplitudes for covered versus. uncovered faces; increased LPP amplitudes to the self-face versus. other faces). LDA results, in turn, indicated that even partial information about the three types of faces that was available for processing was sufficient to develop an algorithm that subsequently discriminated efficiently uncovered self-, close-other's and unknown faces. Moreover, LDA trained on full images of faces was also able to correctly discriminate images of those faces with surgical-like masks.

Enhanced P100, P300, and LPP amplitudes for covered versus. uncovered faces may reflect amplified attentional processing of faces with surgical-like masks. Specifically, P100 is traditionally related to the early processes of stimulus detection and to sensory gain control (Mangun, 1995). This sensory gain control mechanism is manifested either as attentional suppression or as attentional facilitation, occurring at an early stage of information processing (Hillyard et al., 1998). Based on the notion that the P100 amplitude is proportional to the amount of attentional resources required for initial processing of visual information (Hillyard & Anllo-Vento, 1998; Mangun & Hillyard, 1991), increased P100 amplitudes and delayed P100 latencies to faces with surgical-like masks may indicate stronger but slightly delayed involvement of early selective attention.

Increased P100 to faces with masks may also be directly related to the view that visual ambiguity is associated with enhanced P100 (Schupp et al., 2008). In line with this notion, P100 amplitude was larger for morphed faces than for unaltered faces (Dering et al., 2011) and for inverted faces when compared to upright faces (Hileman et al., 2011). However, some studies reported not only larger P100 amplitude but also a longer P100 latency for inverted faces when compared to upright faces (Itier & Taylor, 2002). An analogous pattern of P100 results was observed in the present study. Both the inversion of a face and its covering with a surgical-like mask lead to a disruption of its configural processing, making it more difficult to identify a face as a face and thus requiring increased attention (Itier & Taylor, 2002). In addition, it has also been proposed that the P100 component may serve as a sign of processing effort (Hileman et al., 2011). Thus, the higher P100 amplitude and the longer latency to faces with masks than to faces without masks may reflect the need for engagement of additional brain resources.

The P300 component, in turn, reflects the cognitive evaluation of stimulus significance, a process that can be elicited by both active and passive attention (Picton & Hillyard, 1988). As the functional role of P300 is associated mainly with allocation of attentional resources (Polich, 2007), substantially enhanced P300 amplitudes for covered faces reflected increased attention allocation. Subsequently, LPP is linked to a global, temporary increase in attention that serves to facilitate the in-depth processing of salient stimuli (Brown et al., 2012;

Hajcak et al., 2010). In the light of this, increased LPP to faces with surgical-like masks reflects enhanced processing and global sustained attention. In addition, as far as the saliency feature of stimuli is concerned, larger LPP amplitudes to all faces with surgical-like masks than to faces without masks may be a consequence of an increased arousal associated with processing of covered faces (Cuthbert et al., 2000). All in all, the detection of faces with surgical-like masks was associated with the more elaborated attentional processing, and mask-covered faces were focused on by participants to a significantly greater extent than fully visible faces.

While the early ERP components (P100, N170) were not modulated by the type of presented face, it was the case for late ERP components (P300, LPP) that showed such effect. Our results corroborate the findings of previous studies reporting enhanced P300 (Cygan et al., 2014; Kotlewska & Nowicka, 2015; Ninomiya et al., 1998; Sui et al., 2006; Tacikowski & Nowicka, 2010) and enhanced LPP (Żochowska et al., 2021) to the self-face in comparison to other (either familiar or unfamiliar) faces. However, in the current study we showed, for the first time that both the full view of the self-face as well as only the upper part of the self-face available for processing resulted in increased P300 and LPP amplitudes in comparison to other (personally relevant and personally irrelevant) faces. This self-preference effect may be also attributed to highly elaborated attentional processing of the self-face (Tacikowski & Nowicka, 2010; Żochowska et al., 2021). Thus the mechanisms boosting the prioritized processing of self-relevant information seem to be driven by automatic capture of attention and prioritized allocation of attention to the self-related stimuli (review: Humphreys & Sui, 2016; Sui & Rotshtein, 2019). Indeed, several studies found that self-face automatically captures attention (e.g., Alexopoulos et al., 2012; Alzueta et al., 2020; Brédart et al., 2006; Tong & Nakayama, 1999) and numerous ERP studies revealed greater amplitude of the P300 component in response to one's own face (e.g., Knyazev, 2013; Ninomiya et al., 1998; Sui et al., 2006; Tacikowski & Nowicka, 2010; Żochowska et al., 2021).

Enhanced LPP to the self-face reported in the present study may be attributed either to the global, temporary increase in attention (Brown et al., 2012; Hajcak et al., 2010) or to the process of self-reflection. The later interpretation is based on commonly reported larger LPP when participants make judgments about themselves compared to making judgments about others (Kotlewska & Nowicka, 2016; Nowicka et al., 2018; Yu et al., 2010; Zhang et al., 2013). It is worth noting that in the current study a single experimental trial was long enough to allow for such mental activity, i.e., some considerations about one's own person. Although no kind of self-reflection was required to successfully accomplish the behavioral task (a simple detection of faces), one may assume that multiple presentations of one's own face may automatically evoke such a process. This notion is supported by the findings of fMRI studies (Heatherington et al., 2006; Keenan et al., 2000; Kircher et al., 2001), reporting an increased activation of the medial prefrontal cortex and anterior cingulate cortex to images of self-faces compared with images of others' faces. These findings may indicate that exposure to the self-face effectively induces introspection and emotional reaction.

We would also like to point out the non-significant interactions of face type (self, close-other's, unfamiliar) and

stimulus type (face with mask, face without mask) in our analyses of P300 and LPP amplitudes, indicating that patterns of P300 and LPP results regarding type of faces were analogous for faces with and without masks. Whether or not the faces were covered by masks, amplitudes of P300 and LPP to one's own face were the largest, followed by amplitude to the close-other's face and lastly unfamiliar faces. This pattern of findings for fully visible faces was reported in previous studies on self-face processing (e.g., Cygan et al., 2014; Kotlewska & Nowicka, 2015; Żochowska et al., 2021). However, the observed impact of familiarity on P300 and LPP findings to faces with masks seems to suggest some differentiation of faces even if they were processed in a feature-based way.

The next issue that we would like to comment on refers to similarities between neural correlates of faces with and without surgical-like masks. First of all, amplitudes of N170 were not different for faces with and without surgical-like masks. Numerous studies showed that the N170 component is enhanced for faces compared to other non-face objects (e.g., Rossion & Jacques, 2011). Thus it is claimed to be face-specific (e.g., Bentin et al., 1996; Sagiv & Bentin, 2001; Carmel & Bentin, 2002) and to reflect the structural encoding of faces (e.g., Eimer, 2000; for a review, see; Eimer, 2011). The N170 is usually linked to the activation of perceptual face representations (Eimer, 2000; Sagiv & Bentin, 2001). Moreover, the N170 involves the detection of a face at a categorical level, i.e., its discrimination from another object category (Schweinberger & Neumann, 2015). Thus, similar amplitudes for covered and uncovered faces may indicate similar levels of structural encoding and a similar categorization of faces with surgical-like masks as faces. The findings of some earlier studies (Eimer, 2000) indicated attenuated N170 amplitudes for faces lacking some of their natural features (e.g., eyes, nose etc.). In contrast, disruption in the use of configural information for inverted faces was associated with larger N170 as compared to N170 to upright faces (e.g., Rossion et al., 2000; Civile, et al., 2018). Thus, although both removing some essential parts in face images and presenting face images in the atypical position disturbed the holistic processing of faces, those two manipulations were associated with opposite N170 effects: either a decrease or increase in N170 amplitudes. In the present study, in turn, similar N170 amplitudes were found to fully visible faces and to faces with masks, processed in a more featural manner. It may be hypothesized that nowadays covering the lower part of a face with a surgical-like mask is so common that such a face image may be treated as an ecologically valid stimulus and may be viewed as a face. It should be pointed out that although all of aforementioned face manipulations promote feature-based processing, there is one crucial difference between them. In the case of inverted faces, all pieces of information about a face (eyes, nose, mouth, forehead, face shape, cheeks etc.) are still available for processing. In the case of faces with masks or faces and faces lacking some internal features, only partial information about the face is processed. Therefore, outcomes of studies with different face manipulations may differ.

In addition, there is strong evidence indicating that only the self-face (but no other familiar face) is processed using featural information (Keyes, 2012; Keyes & Brady, 2010). However, we did not observe any differences in the amplitude

of N170 between the mask-covered self-face and other faces. Moreover, we found no differences between fully visible images of the self-, close-other's, and unfamiliar faces either. The latter is in line with findings of studies revealing that the N170 is rather not affected by face familiarity: similar N170 potentials were elicited by famous and unfamiliar faces (Gosling & Eimer, 2011; Tacikowski et al., 2011), both when they were relevant and irrelevant to the task (Bentin & Deouell, 2000). Although some studies have presented evidence that this component is larger (i.e., more negative) to the self-face when compared to other faces, familiar or not (Caharel et al., 2002; Keyes et al., 2010), this pattern of findings was not confirmed by other studies (Gunji et al., 2009; Parketny et al., 2015; Pierce et al., 2011; Sui et al., 2006; Tanaka et al., 2006).

The results of two LDA models also revealed some similarities in processing faces with and without surgical-like masks. Specifically, irrespective of whether the algorithm was trained to discriminate self-face, close-other's face, and unknown faces either with or without surgical-like masks, it was able to effectively discriminate faces that were not presented in the training phase. Based on LDA results, one may conclude that neural activity associated with processing of information about upper parts of face was sufficient to decode full images of faces. It should be stressed, however, that the LDA algorithm may not directly reflect how the human brain works. Thus, the fact the LDA can effectively discriminate faces that were not presented in the training phase is not necessarily relevant to a human being able to do so. Our LDA findings are generally in line with a recent study that investigated facial expression of different emotions in the case of faces covered by masks or scarfs (Calbi et al., 2021). Despite the covering of the lower part of the face, participants correctly recognized the facial expressions of emotions. Although we tested different face-identities and Calbi et al. (2021) tested different facial emotions, both studies found that the upper part of the face provided enough information to be sufficiently and adequately processed.

Similarities in the processing of faces with and without surgical-like masks were also revealed by sources analyses of recorded activity. In both cases, sources were located in fusiform gyri, typically involved in processing of faces (Kanwisher et al., 1997; Kanwisher & Yovel, 2006; Rossion et al., 2003). The latter is in line with findings of some fMRI studies showing equally strong activations in this region both for entire human faces and for faces with eyes occluded (Tong et al., 2000). Our results showing sources located in the fusiform gyri for covered faces may be viewed as providing evidence that upper part of a face is treated just as a face and for that reason activates fusiform gyri. An alternative explanation may refer to the expertise hypothesis (Burns et al., 2019; Gauthier et al., 2000), proposing that the fusiform face area responds not only to faces but to view of stimuli for which participants have gained substantial perceptual expertise. In light of the expertise hypothesis, our findings may be explained by a newly developed expertise to process/recognize a partial view of faces.

On the behavioral level, we found that RTs were not modulated by the face type in general. Specifically, RTs to the self-face did not significantly differ from RTs to other

faces. This result is in line with a recent meta-analysis across a large number of studies (Bortolon & Raffard, 2018). Bortolon and Raffard (2018) stressed that the employed task and, more precisely, the cognitive function on which that task rests may have an impact on patterns of RTs findings. When performing a detection task or visual search task that relies on attentional processes, participants responded equally quickly to their own face and to other people's faces. On the other hand, when requested to perform an identification task, participants were faster when responding to their own face than to other people's faces (Bortolon & Raffard, 2018).

However, we observed, a clear differentiation of the self-face with and without a surgical-like mask, with shorter RTs in the unmasked condition. We hypothesize that this slowing of reaction to one's own face when covered by a mask may correspond to emotional Stroop-like RTs effect (Dresler et al., 2009). The slowing of responses to the color of emotional stimuli in comparison to neutral ones indicates a biasing of attentional resources towards emotionally salient information (González-Villar et al., 2014). Thus, longer RTs to the self-face when covered by a mask may be a consequence of a specific attentional bias to the unusual image of one's own face. At this point it should be stressed that our behavioral task did not require overt recognition of the presented faces, and we could not directly infer that the face recognition occurred. Nevertheless, one may assume that this is a rather automatic process that happens involuntary. In a similar vein, Bortolon and Raffard (2018) noted also that the extraction of semantic information (e.g., face identity or face familiarity) also takes place during detection (attentional) tasks because we automatically attach meaning to what we see, although the task itself does not require the extraction of this information to be successful.

In conclusion, early (P100) and late (P300, LPP) ERP components revealed the stronger involvement of attentional mechanisms in processing of faces covered by surgical-like masks. However, N170 amplitudes as well as the results of LDA and source analyses pointed to some similarities between the neural underpinnings of faces when observed with and without surgical-like masks.

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Credit author statement

Anna Żochowska: Conceptualization, Investigation, Formal analysis, Visualization, Writing - Review & Editing. **Paweł Jakuszyk:** Conceptualization, Investigation, Formal analysis, Visualization, Writing - Review & Editing. **Maria Nowicka:** Data Curation, Formal analysis, Software, Visualization, Writing - Review & Editing. **Anna Nowicka:** Conceptualization, Methodology, Resources, Supervision, Project administration, Funding acquisition, Writing - Original Draft, Writing - Review & Editing.

Others

- Data, experiment code and analysis code can be found here: <https://osf.io/a9wef/>
- Legal copyright restrictions do not permit us to publicly archive the stimuli from The Chicago Face Database (CFD) used in this experiment. Readers seeking access to the stimuli are advised to visit <https://www.chicagofaces.org/>. CFD stimuli will be provided on request without restriction. Furthermore, a subset of experimental stimuli presenting images of participants' faces and their close-others' faces have not been archived in a publicly accessible repository in order to maintain participant anonymity and ethics reasons (participants were assured that their faces will neither be publicly available nor used in other studies).
- No part of the study procedures and analyses were pre-registered in a time-stamped, institutional registry prior to the research being conducted.
- We report how we determined our sample size, all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures in the study.

Open practices

The study in this article earned an Open Data badge for transparent practices. Data for this study is available at https://osf.io/a9wef/?view_only=63bc4f0eef6a41359fce6f0976db516c.

Declaration of competing interest

None.

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Publication 3

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OŚWIADCZENIE

Jako pierwszy autor artykułu:

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oświadczam, że mój wkład w powstanie tej publikacji polegał na:

- współudziale w opracowaniu koncepcji badania
- opracowaniu procedury eksperymentalnej
- napisaniu skryptu w PRESENTATION do prezentacji bodźców wzrokowych z zaprogramowaniem losowej sekwencji bodźców oraz z wysyłaniem znaczników bodźców do oprogramowania rejestrującego sygnał EEG
- wygenerowaniu części bodźców wzrokowych (abstrakcyjnych kształtów) o takiej samej charakterystyce, jak zdjęcia twarzy (dotyczyło to wysokości i szerokości, powierzchni, luminacji)
- przygotowaniu indywidualnego zestawu bodźców wzrokowych dla każdej osoby badanej (wchodziły w ten zestaw m. in. zdjęcia twarzy własnej i twarzy osoby bliskiej, które musiały być dopasowane do założonego rozmiaru, wyrównana musiała być ich luminacja i kontrast)
- rekrutacji osób badanych
- przeprowadzeniu wszystkich badań z rejestracją EEG
- analizie danych elektrofizjologicznych z wykorzystaniem metody potencjałów wywołanych
- analizie statystycznej amplitud potencjałów wywołanych
- analizie statystycznej danych behawioralnych
- współudziale w analizie danych EEG z wykorzystaniem testów permutacyjnych
- współudziale w interpretacji i dyskusji wyników
- opisaniu procedury i metody

- zaplanowaniu prezentacji graficznej uzyskanych wyników
- przygotowaniu części rycin do publikacji
- współudziale w pisaniu manuskryptu
- korekcie i uzupełnianiu finalnej wersji manuskryptu

Anna Zochowska

Warszawa, 31.08.2023

Mgr Paweł Jakuszyk

Pracownia Obrazowania Mózgu

Instytut Biologii Doświadczalnej im. M. Nenckiego

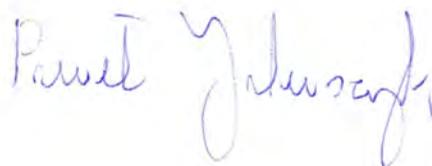
OŚWIADCZENIE

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oświadczam, że mój wkład w powstanie tej publikacji polegał na pomocy technicznej w przeprowadzeniu badań z rejestracją EEG (przygotowanie czepka z elektrodami, zaś po założeniu czepka na głowę osoby badanej – aplikacja żelu w celu zmniejszenia oporności, mycie elektrod) oraz współudziale w analizie danych behawioralnych i elektrofizjologicznych.

Wyrażam zgodę na przedłożenie w/w pracy przez mgr Annę Żochowską jako części rozprawy doktorskiej w formie spójnego tematycznie cyklu artykułów opublikowanych w czasopiśmie naukowym. Oświadczam, że w/w publikacja lub wyniki wchodzące w jej skład nie będą stanowić części mojej rozprawy doktorskiej.



Warszawa, 31.08.2023

Dr Maria Nowicka

OŚWIADCZENIE

Jako współautorka pracy:

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oświadczam, że mój wkład w powstanie tej publikacji polegał na pomocy technicznej w przeprowadzeniu części badań z rejestracją EEG, przeprowadzeniu analiz z wykorzystaniem testów permutacyjnych oraz przygotowaniu części rycin do publikacji.

Jednocześnie wyrażam zgodę na przedłożenie w/w pracy przez mgr Annę Żochowską jako części rozprawy doktorskiej w formie spójnego tematycznie cyklu artykułów opublikowanych w czasopismach naukowych.

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Warszawa, 12.09.2023

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OŚWIADCZENIE

Jako promotor mgr Anny Żochowskiej oraz współautor pracy:

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oświadczam, że publikacja ta powstała w ramach realizacji kierowanego przeze mnie grantu OPUS (nr 2018/31/B/HS6/00461). Moja rola w powstaniu tej publikacji polegała na ustaleniu koncepcji badania i zaprojektowaniu schematu badania, sprawowaniu nadzoru merytorycznego, konsultowaniu analizy danych, dyskusji i interpretacji uzyskanych wyników oraz współudziale w pisaniu manuskryptu.

Anna Nowicka

The self and a close-other: differences between processing of faces and newly acquired information

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Prioritization of self-related information (e.g. self-face) may be driven by its extreme familiarity. Nevertheless, the findings of numerous behavioral studies reported a self-preference for initially unfamiliar information, arbitrarily associated with the self. In the current study, we investigated the neural underpinnings of extremely familiar stimuli (self-face, close-other's face) and stimuli newly assigned to one's own person and to a close-other (abstract shapes). Control conditions consisted of unknown faces and unknown abstract shapes. Reaction times (RTs) to the self-face were shorter than to close-other's and unknown faces, whereas no RTs differences were observed for shapes. P3 amplitude to the self-face was larger than to close-other's and unknown faces. Nonparametric cluster-based permutation tests showed significant clusters for the self-face vs. other (close-other's, unknown) faces. However, in the case of shapes P3 amplitudes to the self-assigned shape and to the shape assigned to a close-other were similar, and both were larger than P3 to unknown shapes. No cluster was detected for the self-assigned shape when compared with the shape assigned to the close-other. Thus, our findings revealed preferential attentional processing of the self-face and the similar allocation of attentional resources to shapes assigned to the self and a close-other.

Key words: self-preference; attention; saliency; familiarity; ERP.

Introduction

In order to ensure our adaptive functioning in complex social environments, only some pieces of incoming information are selected for further processing. Such selection is often guided by the self-relevance of the information (Sui and Rotshtein 2019). To start with, a classic example of preferential self-processing is the cocktail party effect (Moray 1959). During a noisy party, even when engaged in an immersive conversation, we can easily hear our own name in the otherwise meaningless noise of other people's conversations. Numerous studies showed prioritized processing not only of one's own name (Tacikowski and Nowicka 2010; Yang et al. 2013; Nowicka et al. 2016; Nijhof et al. 2018; Doradzińska et al. 2020) but also for one's own face (Brédart et al. 2006; Ma and Han 2010; Miyakoshi et al. 2010; Tacikowski and Nowicka 2010; Tacikowski et al. 2011; Kotlewska and Nowicka 2015; Bola et al. 2021; Żochowska et al. 2021). Thus, self-relevance facilitates stimulus processing at different levels: items linked with the self are easier to notice, evaluate, and remember when compared to material associated with other people (e.g. Symons and Johnson 1997; Keyes and Brady 2010; Kotlewska and Nowicka 2016; Nowicka et al. 2016).

Importantly, in the cited studies self-related stimuli were represented by highly familiar items like one's own name or face. The daily exposure to one's own face

and name across the whole lifespan determines their extreme familiarity in comparison with all other faces and names. Hence, it cannot be clearly differentiated whether the observed effects were caused by the self-relevance or familiarity of those stimuli (Butler et al. 2013; Woźniak et al. 2018; Woźniak and Knoblich 2019; Orellana-Corrales et al. 2021).

To control for the confounding effects of familiarity, Sui and colleagues (Sui et al. 2012) introduced an experimental paradigm that arbitrarily assigned new stimuli to the self and other people. In this task, people formed associations between neutral stimuli (equally familiar) and personally significant labels. Specifically, participants were instructed to associate geometric shapes (e.g. a triangle, a circle, and a square) to the self, a friend, and an unknown other. Subsequently, participants were asked to indicate whether a shape-label pair matched the learned assignment. Response times (RTs) were typically significantly faster for congruent combinations of the self-associated shape and label than when responding to any other shape-label combination. A large prioritization effect was observed not only in RTs, but also in accuracy and sensitivity scores for self-shapes when compared to those of a friend or stranger (Sui et al. 2012; Schäfer et al. 2015; Schäfer et al. 2016; Orellana-Corrales et al. 2021). The immediate and substantial advantage for the self- vs. other pair

that was originally reported by Sui and colleagues (Sui et al. 2012) has since been replicated in numerous studies (Frings and Wentura 2014; Mattan et al. 2015; Macrae et al. 2017; Yin et al. 2019).

All in all, a brief association of a neutral shape with the self seems to increase the salience of those stimuli and is sufficient to elicit the self-prioritization effect (Schäfer et al. 2015; Schäfer et al. 2016; Wang et al. 2016; Woźniak and Knoblich 2019). Self-prioritization is thought to influence multiple stages of information processing within matching tasks—the allocation of attention, memory (the retrieval of a self-representation), and decision-making processes (Sui and Humphreys 2015; Humphreys and Sui 2016; Liu et al. 2016). However, the most important account of such self-prioritization is that the effects are driven by tuning attention toward self-related information, i.e. self-relevance modulates attentional processing (Sui and Rotshtein 2019).

However, it is worth noting that in trials with matching pairs of self-associated shape and self-label, participants were processing both self-associated arbitrary stimuli and familiar verbal labels with an established meaning. Therefore, the self-advantage may be caused by the high familiarity of the self-label and not by the self-association of the shape. This fact led some studies to test self-prioritization effects in experimental paradigms with new self- vs. other-associated stimuli only. For example, Sui et al. (2009) associated colors to the self vs. a friend first and then presented arrows in the associated colors at the center of the screen, which served as either valid or invalid cues for the subsequent target location. Arrows in the self-associated color were more efficient in guiding attention than arrows in the friend-associated color. In a similar vein, saccades toward targets positioned away from self vs. other-associated shapes were initiated more slowly (Dalmaso et al. 2019). Moreover, the cuing of target locations by newly self-associated stimuli enhanced target detection (Wade and Vickery 2018; but see Siebold et al. 2015). Finally, the self-prioritization effect could be elicited even in a matching task that employed exclusively neutral stimuli (Woźniak and Knoblich 2019). In that study, participants were first asked to associate avatar faces with three identities: self, friend, and stranger. Afterwards, participants were asked to associate unfamiliar abstract symbols with those three identities. Thus, instead of face-familiar label pairs, pairs of avatar faces, and abstract shapes were presented in a perceptual matching task. Nevertheless, a clear self-prioritization was observed, revealing that this effect can be elicited in the absence of any familiar stimuli. In yet another study, self-prioritization was investigated in an adapted perceptual matching task in which participants were instructed to associate arbitrary stimuli pairs (shape and color) with different people, and then immediately carried out a color-shape matching task. The results showed again the standard pattern of the self-prioritization effect, confirming that the effect is not critically dependent on familiar labels (Lee et al.

2021). In line with the later findings, such effect was observed in a modified matching task, in which familiar labels from the standard task were replaced with pseudo-words, i.e. in the absence of any stimuli with established self-associations (Woźniak and Knoblich 2021). However, it was found only if self-associations were presented as task-relevant (Woźniak and Knoblich 2021).

Most studies investigating the self-prioritization of information that was newly assigned to one's self vs. another person were based on behavioral measures (RT, accuracy, sensitivity scores). In contrast, studies investigating the neural correlates of such information processing are rather rare (Sui et al. 2013; Sui et al. 2015b; Woźniak et al. 2018). One of the first studies in this field used an associative learning procedure (Sui et al. 2013) that instructed participants to assign three neutral shapes with labels for themselves, their best friend, and an unfamiliar other. Functional magnetic resonance imaging (fMRI) data were acquired while participants judged whether the shape-label pairs matched or not. Behaviorally, faster responses and higher accuracy were found for self-assigned pairs. Responses to matching self-pairs were associated with enhanced activity in the ventral medial prefrontal cortex (vmPFC)—a brain region linked to self-representation (Northoff and Berman 2004; Northoff et al. 2006; Denny et al. 2012)—and in the posterior superior temporal sulcus, which is linked to social cognition (Beauchamp 2015). Activations in those two brain regions predicted behavioral self-bias effects.

In yet another fMRI study (Sui et al. 2015b), participants associated shapes with either themselves or a friend. Subsequently, the shapes had to be identified in hierarchical (i.e. global-local) forms. Self-assigned stimuli were associated with increased activation of the left inferior parietal sulcus when the task required participants to select the neutral shape and ignore the self-associated shape (i.e. salient self-distractors had to be rejected). Since a similar increase in activation in the same region was found when participants rejected perceptually salient distractors (Mevorach et al. 2009), it seems that rapidly formed self-associations may change the neural response in a manner that is qualitatively similar to effects produced by changing the perceptual saliency of stimuli (Sui et al. 2015b).

Further, in an event-related potential (ERP) study three unfamiliar faces were identified with the verbal labels “You,” “Friend,” and “Stranger” instead of shapes (Woźniak et al. 2018). Afterwards, participants judged whether two stimuli (i.e. face, label) presented in succession matched. In one experiment faces were followed by verbal labels, whereas in the other experiment, labels were followed by faces. Both experiments showed an analogous pattern of behavioral and ERP results. If the first stimulus (face or label) was self-related, RTs were faster and the late frontal positivity to the first stimulus was more pronounced. Moreover, the central-parietal P3 associated with the second stimulus was more pronounced when it was preceded by any

self-related stimulus. However, when the first stimulus was not associated with the self, there was no facilitation in the processing of the second stimulus even if it had an intrinsic association with the self (Woźniak et al. 2018). Thus, two primary conclusions can be drawn: (1) the self-relevance of initially encountered information has a decisive role in the processing of subsequent information, and (2) self-associated stimuli facilitated the processing of subsequent stimuli, irrespective of whether these stimuli were associated with the self.

In the current ERP study, we investigated the neural underpinnings of highly familiar and new information that was arbitrarily assigned to the self and to a close-other. We were interested in whether previously irrelevant, abstract information that was newly associated with the self would benefit from preferential processing as is the case for well-known self-referential information, and whether self-prioritization effects would be comparable in both cases. Therefore, we directly compared the processing of two types of stimuli: extremely familiar (self-face, close-other's face) stimuli, and stimuli that were newly assigned to one's own person and to a close-other (an abstract shape). The control conditions consisted of unknown faces and unknown abstract shapes. We decided to present participants with abstract shapes alone, without labels. The reason for doing so was twofold. First, this approach avoids the aforementioned controversies regarding familiar labels. Second, as there was no need to use any labels in the case of faces, this approach (i.e. avoiding labels) guaranteed similar visual stimulation in both cases.

Participants were tasked with indicating whether presented stimuli (faces, shapes) were familiar or unknown. Prior to the EEG recording session, arbitrarily selected shapes were associated with the self and a close-other (i.e. one shape for each person). The close-other was freely chosen by each participant as representative of the most significant person in their life at the time of experimentation. This operationalization of a close-other was used in several previous studies on the topic of self-prioritization (Cygan et al. 2014; Kotlewska and Nowicka 2015; Kotlewska and Nowicka 2016; Nowicka et al. 2016; Kotlewska et al. 2017; Nijhof et al. 2018; Nowicka et al. 2018; Cygan et al. 2021). It is worth noting that similarly to one's own face, a close-other's face is a very important and salient visual stimulus that is frequently encountered on an everyday basis. Thus, its level of familiarity is very high. Nevertheless, on the neural level the processing of such extremely familiar faces—with a very high exposure factor—substantially differs from the processing of the self-face as revealed by steady-state visual evoked potentials (Kotlewska et al. 2017) and late ERP components, especially P3—a positive ERP component with centro-parietal distribution and latency of 300 ms or longer (Cygan et al. 2014; Kotlewska and Nowicka 2015; Cygan et al. 2021).

In this study, the P3 results obtained for faces served as a kind of reference for ERP results for shapes. We

expected to observe enhanced P3 associated with self-face processing when compared to close-other and unknown face processing. We aimed at testing whether information newly assigned to the self and a close-other would lead to an analogous pattern of findings. As far as behavioral indices of self-prioritization are also concerned, we were interested in whether behavioral findings would be comparable for faces and shapes.

Moreover, the distinct spatial patterns of activity elicited by faces and shapes were also tested with nonparametric cluster-based permutation tests (Maris and Oostenveld 2007). This method enables the unbiased comparison of EEG signals recorded in different experimental conditions at all sensors and all time points, while controlling for multiple comparisons and maximizing power by employing the cluster structure of the data as its sole test statistic. We used this approach to test for differences in spatial and temporal distributions between experimental conditions. Thus, cluster-based permutation tests would confirm and complement the findings obtained with P3 analyses, providing a global and complete view of commonality/distinctiveness in the neural underpinnings associated with the processing of self-, close-other, and unknown faces and newly acquired information referring to the self, a close-other, and unknown people.

Materials and methods

Participants

Thirty-two participants (16 females, 16 males) were tested in the study, ranging in age between 21 and 34 years old ($M = 27.594$; $SD = 3.131$). The Edinburgh Handedness Inventory (Oldfield 1971) indicated that thirty participants were right-handed. All participants reported no history of mental or neurological disorders and had normal or corrected-to-normal vision with the use of contact lenses. Additionally, to ensure the uniformity of visual stimuli standards, neither participants nor their chosen close-other were allowed to be represented with glasses or have any distinctive facial marks, as their photographs were matched with photographs from the Chicago Face Database (CFD; Ma et al. 2015).

An additional present-day restriction was a negative test for the SARS-CoV-2 virus. As all participants were PhD students and employees at the Nencki Institute, they took part in the SONAR-II project (www.nencki.edu.pl) developed at the Nencki Institute in cooperation with the University of Warsaw. SONAR-II is dedicated to the asymptomatic population of people who do not meet the criteria for SARS-CoV-2 testing but who may come into contact with infected people.

The required sample size was estimated using MorePower software (Campbell and Thompson 2002). Estimation was conducted for the main factor “type of stimuli” (face, shape) in two-way repeated measures ANOVA with the factors “type of stimuli” and “type of face” (self, close-other's, unknown): estimated effect size $\eta^2 = 0.25$, $\alpha = 0.05$,

$\beta = 0.90$. It yielded a sample size of 30 participants. As the risk of data loss was taken into consideration, the group size was enlarged to 32.

Ethics statement

This study was conducted with the approval of the Human Ethics Committee of the Institute of Applied Psychology at Jagiellonian University (Cracow, Poland). All participants provided written informed consent prior to the study and received financial compensation for their participation.

Stimuli

We used two different types of stimuli in this study: (1) faces and (2) shapes. The set of stimuli was individually tailored to each participant. Faces belonged to three categories: self-face, close-other's face, and unknown faces. Participants freely chose the close-other according to their subjective high level of closeness and importance. We did not predefine the type of relationship between the participant and their close-other in order to avoid a spuriously close relation. The only restriction placed on the selection of the close-other was that they had to be of the same gender as the participant. Twenty-two participants chose their friend, eight their sibling, and two their partner. The face of each participant and their close-other was photographed (with a neutral expression) prior to the study. The photographs of eight unknown neutral faces were taken from the Chicago Face Database (Ma et al. 2015), gender matched to each participant. Each photo (the self-face, close-other's face, and selected unknown faces from the CFD) was subjected to the same editing procedure, i.e. they were gray-scaled, extracted from the background and cropped (only facial features were included—face oval without hair and ears), resized to subtend $6.7^\circ \times 9.1^\circ$ of visual angle, and equalized for mean luminance using Photoshop CS5 (Adobe, San Jose, CA). Contrast and spatial frequencies in the pictures were not normalized as these procedures tend to introduce substantial distortions into the processed images. The photos of each participant and their close-other's face were deleted at the end of the experimental session.

The second type of stimuli consisted of abstract shapes. In previous studies on the processing of new information assigned to the self and others, simple geometric figures (e.g. a square, a triangle) were typically used. As the number of shapes was supposed to be equal to the total number of faces (self, close-other's, 8 unknown) we generated 10 different abstract shapes. We aimed at equalizing low-level physical features of faces and shapes. Thus, each shape's area was equal to face oval's area, i.e. 43.12 cm^2 . Shape assignment to each experimental "condition" (self, close-other, unknown) was pseudo-random on the group level; e.g. a self-assigned shape in a given set of stimuli was assigned to a close-other or unknown condition in some other set of stimuli. Faces and shapes were presented against a

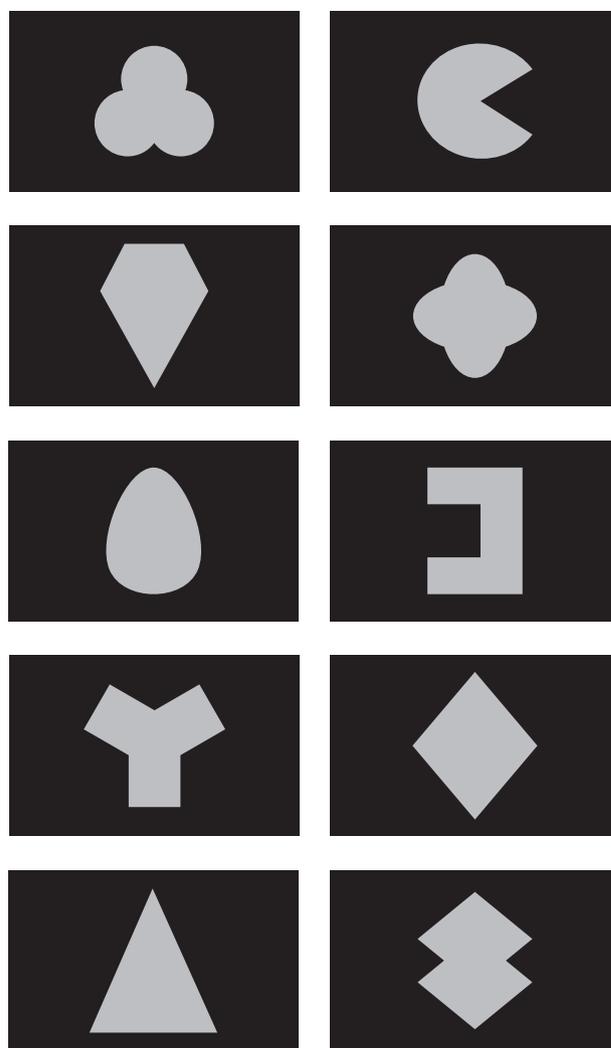


Fig. 1. Shapes used in the present study. The area of each shape was the same and was equal to the area of the face oval.

black background. Figure 1 presents all 10 shapes used in this study.

Procedure

Participants were seated in a comfortable chair in a dimly lit and sound-attenuated room, 57 cm from the computer monitor (DELL Alienware AW2521HFL, Round Rock, Texas, USA). Subsequently, during the electrode cap placement and adjustment of EEG electrode impedances, they were primed for the task: two different shapes, one assigned to the participant and the second to their close-other, were presented on the monitor and participants were required to associate those geometric shapes with the self and chosen close-other. The learning phase lasted on average 23.53 min (SD = 5.900). Just before the beginning of the task, participants were asked to draw the assigned shapes. This was done to check the efficiency of learning.

After electrode cap placement (ActiCAP, Brain Products, Munich, Germany), the participants used an adjustable chinrest to maintain a stable head position. Presentation software (Version 18.2, Neurobehavioral

Systems, Albany, CA) was used for stimuli presentation. Participants performed a recognition task—if they recognized a presented face or shape (i.e. representing the participant or their close-other), they were asked to push the response button assigned to “YES.” If that was not the case, they were asked to press the button defined as “NO.” The assignment of “YES” and “NO” buttons was counterbalanced across the participants.

After reading the instructions displayed on the screen, the subjects confirmed they understood the task and initiated the experiment by pressing a response button. Trials with faces and shapes were inter-mixed (in one session) and their order was pseudo-random with respect to the type of stimulus (faces, shape) and the experimental condition (self, close-other, unknown). Each trial started with a blank screen, presented for 1500 ms. Next, a white fixation cross (subtending $0.5^\circ \times 0.5^\circ$ of visual angle) was centrally displayed for 100 ms and followed by a blank screen which lasted either (randomly) 100, 200, 300, or 400 ms. Afterwards, a face or a shape was presented for 500 ms. Regardless of which stimulus was shown, participants were asked to push the appropriate response button as quickly as possible. Next, a blank screen was shown and lasted until a response was made. The procedure structure is presented in Fig. 2. In the “self” and “close-other” conditions, the total number of repetitions for each stimulus type (face, shape) was 40, while for the “unknown” condition it was 80. Thus, the total number of trials with familiar and unknown stimuli was equal, as was the probability of YES/NO responses.

To account for possible fatigue during the experiment, a break was planned in the middle of experimental session. It was terminated after one minute, unless the participant ended it earlier. Participants needed 24 min on average to complete the whole experiment.

EEG recording

The electroencephalogram (EEG) was continuously recorded with 62 Ag-AgCl electrically shielded electrodes mounted on an elastic cap (ActiCAP, Brain Products, Munich, Germany) and positioned according to the extended 10–20 system, with two additional electrodes placed on the left and right earlobes. The EEG signal was recorded using the BrainAmp MR plus amplifier (Brain Products, Munich, Germany) and digitized at a 500-Hz sampling rate, using BrainVision Recorder software (Brain Products, Munich, Germany). EEG electrode impedances were kept below $10 \text{ k}\Omega$. The EEG signal was recorded against an average of all channels calculated by the amplifier hardware.

Behavioral data analysis

Responses were scored as correct if the appropriate button was pressed within 100–1000 ms of stimulus onset. In order to conduct statistical analyses of behavioral and ERP data in a consistent manner, similarly to our analyses of ERP components, only every other trial with an unfamiliar stimulus was included in the analyses. This

was done because the number of trials with unfamiliar faces (80) and shapes (80) was doubled in comparison to the number of trials with familiar faces and shapes in each familiar (self, close-other) condition (40). Statistical analyses were performed using JASP software (Wagenmakers et al. 2018). Mean accuracy scores and mean RTs were analyzed using repeated measures ANOVA, with the “type of stimulus” (face, shape) and “condition” (self, close-other, unfamiliar) as within-subject factors.

The traditional null-hypothesis significance-testing approach was complemented with Bayesian analysis methods and Bayes factors (BFs) were computed using JASP software (Wagenmakers et al. 2018). BFs were interpreted according to Lee and Wagenmakers (2014) suggestions. Briefly, a BF_{10} between 1 and 3 implies anecdotal evidence in favor of H_1 , between 3 and 10—moderate evidence, between 10 and 30—strong evidence, between 30 and 100—very strong, and higher than 100—extreme evidence. As far as low values of BF_{10} are concerned, a BF_{10} between 0.33 and 1 indicates anecdotal evidence in favor of H_0 , between 0.1 and 0.33—moderate evidence, and between 0.03 and 0.1—strong evidence of the absence of an effect. Finally, a BF_{10} between 0.01 and 0.03 and lower than 0.01 indicates very strong and extreme evidence for the absence of an effect, respectively.

ERP analysis

Off-line analysis of the EEG was performed using BrainVisionAnalyzer software (Brain Products, Gilching, Germany). The 62 channels were re-referenced off-line to the algebraic average of the left and right earlobes, notch filtered at 50 Hz, and band-pass-filtered from 0.1 to 30 Hz using a Butterworth filter. The next step in data pre-processing was the correction of ocular artifacts using Independent Component Analysis (ICA) (Bell and Sejnowski 1995). After each data set was decomposed into maximally statistically independent components, elements representing eye blinks were rejected based on a visual inspection of the component’s map (Jung et al. 2001). Using the reduced component-mixing matrix, the remaining ICA components were multiplied and back-projected to the data, resulting in a set of ocular-artifact-free EEG data.

Afterward, the EEG signal was segmented into 1200 ms epochs, from -200 ms before to 1000 ms after stimulus onset. The subsequent automatic artifact rejection procedure allowed only trials, which fulfilled the following requirements: the maximum permitted voltage step per sampling point was $50 \mu\text{V}$, the maximum permitted absolute difference between two values in the 200-ms-long segment was $100 \mu\text{V}$, the minimal and maximal allowed amplitudes were $-150 \mu\text{V}$ and $150 \mu\text{V}$, and the lowest permitted activity in the 100 ms interval was $0.5 \mu\text{V}$.

Trials with correct responses were subsequently analyzed. In the case of unfamiliar stimuli, only every

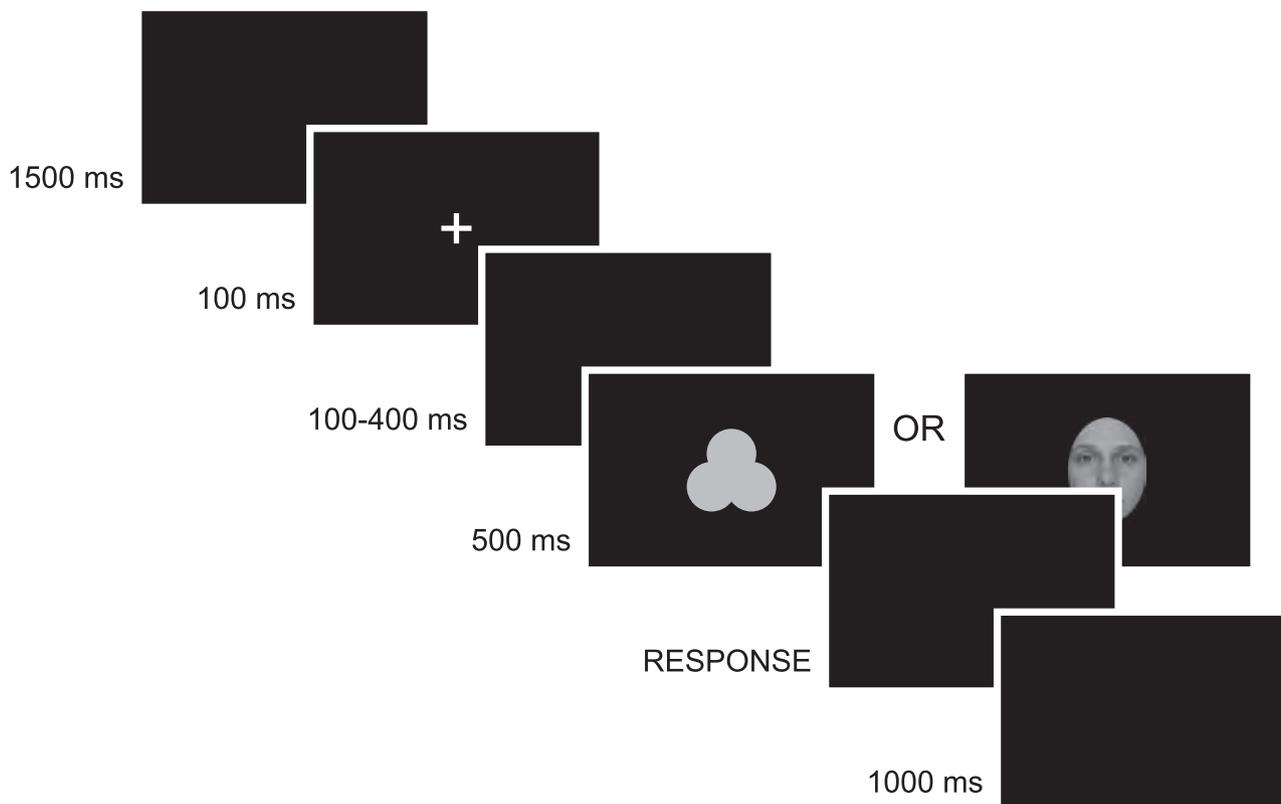


Fig. 2. Schematic presentation of the experimental procedure. Three types of faces (self, close-other's, unknown) and three types of shapes (self-assigned, assigned to the close-other, unknown) were intermixed and presented pseudo-randomly. Participants were supposed to indicate whether a stimulus was familiar or not. The example image of a self-face is a photograph of one of the co-authors.

other trial was included in the analyses. This was done in order to keep a similar signal-to-noise ratio (SNR) for each experimental condition (defined by the type of stimulus and type of face). It should be reminded that the total number of trials with unfamiliar faces and shapes (80 for each of them) was twice as large as the total number of trials with familiar faces and shapes in the single “self” and “close-other” conditions (40 for each type of stimulus). The mean number of segments averaged afterwards for each experimental condition was as follows: self-face—37.031 (SD=2.800), shape assigned to self—35.250 (SD=3.298), close-other's face—36.938 (SD=2.449), shape assigned to close-other—35.031 (SD=3.441), unknown other face—36.344 (SD=2.868), and unknown shape—35.938 (SD=3.816). In the final stage of pre-processing, the epochs were baseline-corrected by subtracting the mean of the pre-stimulus period.

Selection of electrodes for ERP analysis was orthogonal to potential differences between experimental conditions (Kriegeskorte et al. 2009). Therefore, it was conducted on the basis of the topographical distribution of brain activity (in the time window corresponding to a given component), averaged across all experimental conditions. Electrodes CP1, CPz, CP2, and Pz, localized within the region of maximal activity, were selected for further analyses (see Fig. 3). The data were pooled for those electrodes. This step is justified by the limited

spatial resolution of EEG and high correlation between neighboring electrodes. Based on the topographical distribution of activity as well as grand-averaged ERPs, collapsed for all experimental conditions (self-face, shape assigned to the self, close other's face, shape assigned to close other, unknown other face, and unknown shape), a 350–650-ms time window was chosen for analysis of the P3 component. The mean values at each time point within this time window were used to assess the amplitudes of our ERP component. This method is less affected by possible low SNR than peak measure methods (Luck 2005).

Statistical analysis of ERP data was performed using SPSS software (Version 26, IBM Corporation). The reported results were cross-checked with Statcheck (<http://statcheck.io/index.php>). A two-way repeated measure ANOVA was performed with “type of stimulus” (face, shape) and “condition” (self, close-other's, unknown) as within-subject factors. All effects with more than one degree of freedom in the numerator were adjusted for violations of sphericity (Greenhouse and Geisser 1959). Bonferroni correction for multiple comparisons was applied to post hoc analyses. All results are reported with alpha levels equal to 0.05.

The traditional null hypothesis significance testing approach was complemented with Bayesian analysis methods. To test whether the self-face and other faces, as well as the self-assigned shape and other shapes,

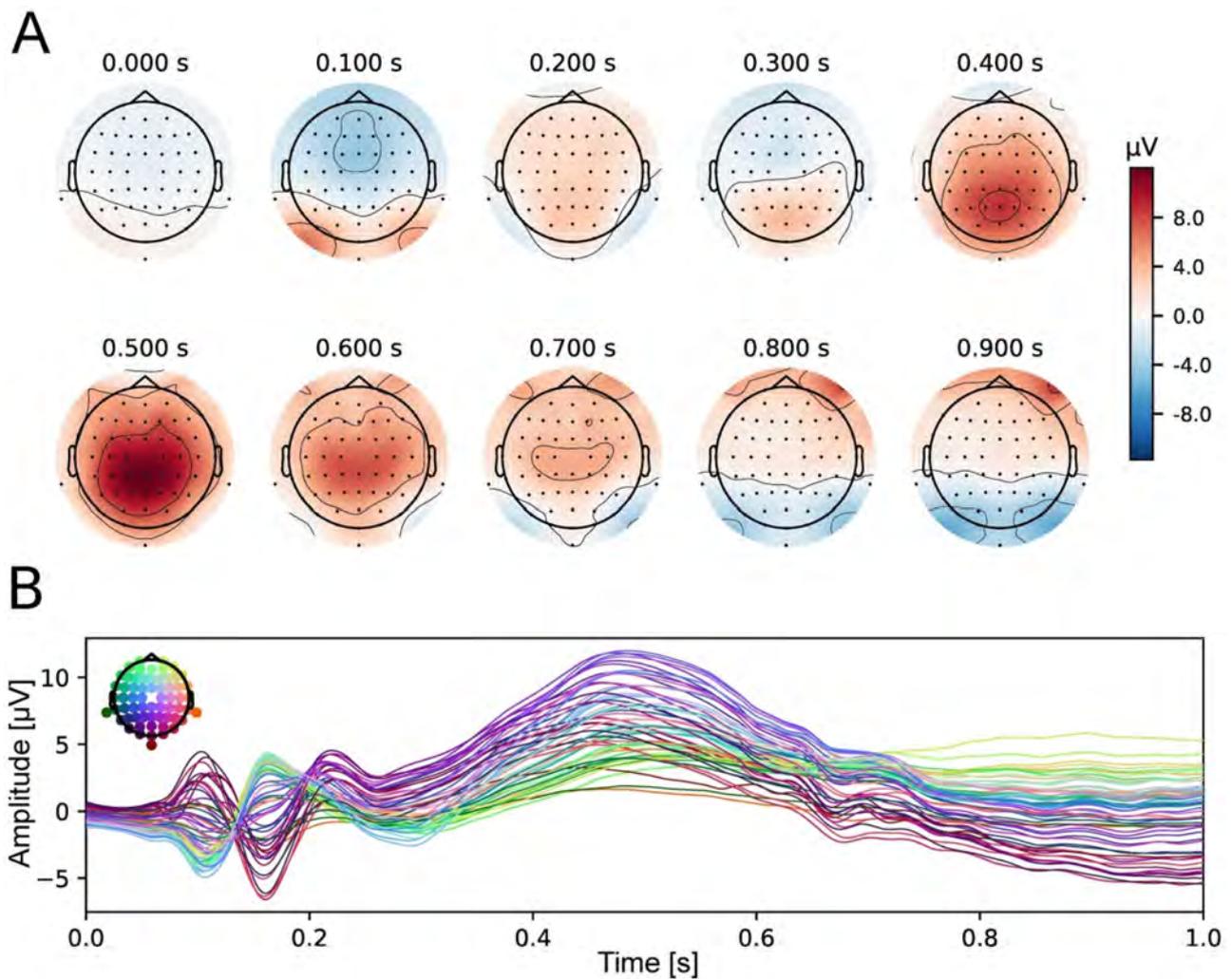


Fig. 3. (A) Topographical distribution of brain activity averaged across the two types of stimuli (faces, shape) and across all experimental conditions (self, close-other, unknown) and (B) a butterfly plot presenting grand-average ERPs for all (collapsed) experimental conditions, at all 62 active electrodes.

were characterized by similar levels of neural activity, BFs were computed using JASP software (Wagenmakers et al. 2018). The main reason for calculating BFs was that, unlike classic frequentist statistics, BF evaluates how strongly both alternative and null hypotheses are supported by the data. Specifically, BF is a ratio of the probability (or likelihood) of observing the data given the alternative hypothesis is true to the probability of observing the data given the null hypothesis is true. Thus, BF_{10} provides further evidence either in favor of similarities or rather differences between the tested experimental conditions. The medium prior scale (Cauchy scale 0.707) was used in all Bayesian tests. BF_{10} were interpreted according to Lee and Wagenmakers (2014) suggestions.

Cluster-based permutation tests

Cluster-based permutation tests were used here as an exploratory analysis procedure, as they efficiently handle the multiple comparisons problem in high-dimensional magnetoencephalographic and EEG data (Sassenhagen

and Draschkow 2019). In general, permutation tests are used to test the null hypothesis that the data in the experimental conditions come from the same probability distribution. Getting a significant result means that the null hypothesis can be rejected in favor of the alternative hypothesis, i.e. that the data came from different distributions. Therefore, significant results from permutations tests indicate a significant between-condition difference. The results are reported with reference to an alpha level equal to 0.05. Cluster-based permutation tests were conducted using custom-made Python scripts with use of the `mne.stats.spatio_temporal_cluster_1samp_test` function from the MNE Python package.

We directly compared: self-face vs. close-other's face, self-face vs. unknown faces, close-other's face vs. unknown faces, self-shape vs. close-other's shape, self-shape vs. unknown shapes and close-other's shape vs. unknown shapes. As clustering in both space and time was used, such an analysis procedure revealed differences in the spatial distributions of activity as a function of time between the tested conditions.

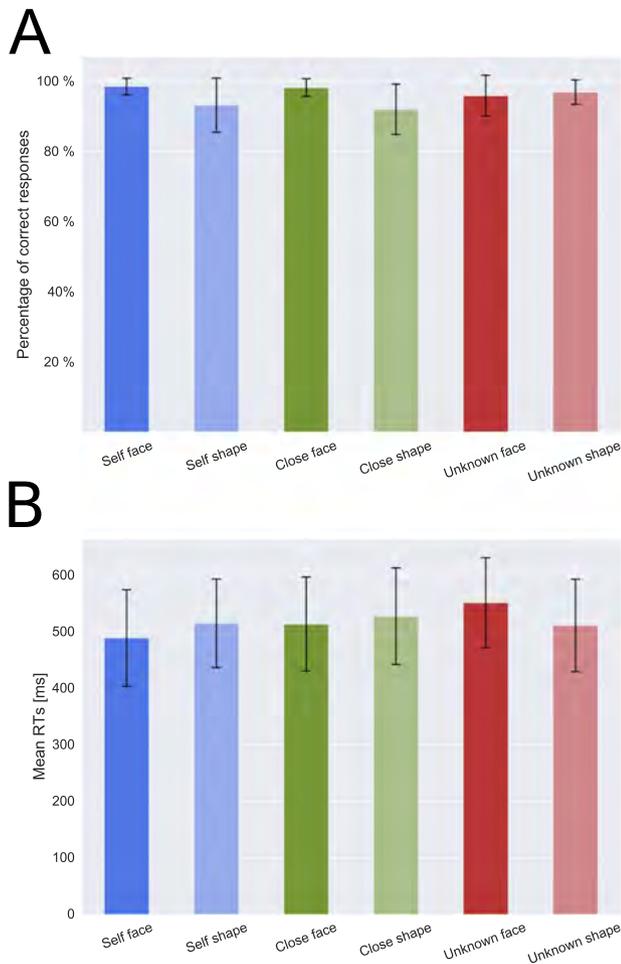


Fig. 4. Behavioral results. (A) Mean (\pm SD) accuracy scores and (B) mean (\pm SD) RTs for faces and shapes.

Results

Behavioral results

A repeated-measures ANOVA conducted on the mean number of correct responses revealed the significant main effects of “type of stimulus” ($F(1, 31) = 28.758$, $P < 0.001$, $\eta^2 = 0.141$) and “condition” ($F(2, 62) = 4.022$, $P = 0.023$, $\eta^2 = 0.028$), as well as a significant two-way interaction: “condition” \times “type of stimulus” ($F(2, 62) = 10.689$, $P < 0.001$, $\eta^2 = 0.119$). The significance of the “type of stimulus” factor indicated a significantly higher accuracy score in the case of faces in comparison with shapes (see Fig. 4). Post hoc tests of the “condition” factor showed that the accuracy score in the “close-other” condition was slightly lower than in the “unknown” condition ($P = 0.020$), whereas other differences were non-significant (“self” vs. “close-other”: $P = 0.808$; “self” vs. “unknown”: $P = 0.282$).

Post-hoc tests of the “condition” \times “type of stimulus” interaction revealed non-significant differences in accuracy scores between the self-face and the close-other’s face ($P > 0.99$, $BF_{10} = 0.231$, moderate evidence for H0), the self-face and unknown faces ($P = 0.933$, $BF_{10} = 0.597$, anecdotal evidence for H0), and the close-other’s face vs. unknown faces ($P > 0.999$, $BF_{10} = 0.541$, anecdotal

evidence for H0). Significant differences in accuracy rates were present between the self-assigned shape and unknown shapes ($P = 0.002$, $BF_{10} = 15.894$, strong evidence for H1) and between the close-other assigned shape and unknown shapes ($P < 0.001$, $BF_{10} = 210.730$, extreme evidence for H1), whereas the self-assigned shape and the close-other assigned shape did not differ ($P > 0.999$, $BF_{10} = 0.256$, moderate evidence for H0).

Moreover, post hoc tests of the “condition” \times “type of stimulus” interaction also showed that the number of correct responses to faces was significantly higher than to shapes in the “self” and “close-other” conditions ($P < 0.001$, $BF_{10} = 50.757$, very strong evidence for H1 and $P < 0.001$, $BF_{10} = 6596.037$, extreme evidence for H1, respectively), but it was similar for faces and shapes in the case of the “unknown” condition ($P > 0.99$, $BF_{10} = 0.297$, moderate evidence for H0).

A repeated-measures ANOVA conducted on mean RTs revealed the significant main effect of “condition” ($F(2, 62) = 25.374$, $P < 0.001$, $\eta^2 = 0.159$) and a significant two-way interaction: “condition” \times “type of stimulus” ($F(2, 62) = 36.036$, $P < 0.001$, $\eta^2 = 0.230$). Post hoc tests of the “condition” factor showed that RTs in the “self” condition were substantially shorter than in the “close-other” ($P < 0.001$) and “unknown” conditions ($P < 0.001$). However, this pattern of findings was driven mainly by RTs to faces. Post hoc tests of the “condition” \times “type of stimulus” interaction revealed significantly shorter RTs to the self-face than to the close-other’s face ($P = 0.001$, $BF_{10} = 4517.073$, extreme evidence for H1) and unknown faces ($P < 0.001$, $BF_{10} = 1.009 \times 10^{10}$, extreme evidence for H1), as well as shorter RTs to the close-other’s face than to unknown faces ($P < 0.001$, $BF_{10} = 5.644 \times 10^6$, extreme evidence for H1). In contrast, in the case of shapes, all differences between conditions were non-significant (self vs. close-other: $P = 0.624$, $BF_{10} = 0.637$, anecdotal evidence for H0; self vs. unknown: $P > 0.99$, $BF_{10} = 0.227$, anecdotal evidence for H0; close-other vs. unknown: $P = 0.105$, $BF_{10} = 2.414$, anecdotal evidence for H1).

Post hoc tests of the “condition” \times “type of stimulus” interaction also showed that RTs to the self-face were significantly shorter than to the self-assigned shape ($P = 0.009$, $BF_{10} = 22.438$, strong evidence for H1). The opposite effect, i.e. longer RTs, was observed for unknown faces when compared to unknown shapes ($P < 0.001$, $BF_{10} = 1.227 \times 10^7$, extreme evidence for H1), but no significant differences were found in the case of the “close-other” condition ($P = 0.908$, $BF_{10} = 0.569$, anecdotal evidence for H0).

P3 results

Statistical analysis of P3 amplitudes revealed the main effects of “type of stimulus” ($F(1, 31) = 27.004$, $P < 0.001$, $\eta^2 = 0.466$), “condition” ($F(2, 62) = 32.288$, $P < 0.001$, $\eta^2 = 0.510$), and a significant 2-way “condition” \times “type of stimulus” interaction ($F(2, 62) = 15.514$, $P < 0.001$, $\eta^2 = 0.334$). The significance of the “type of stimulus”

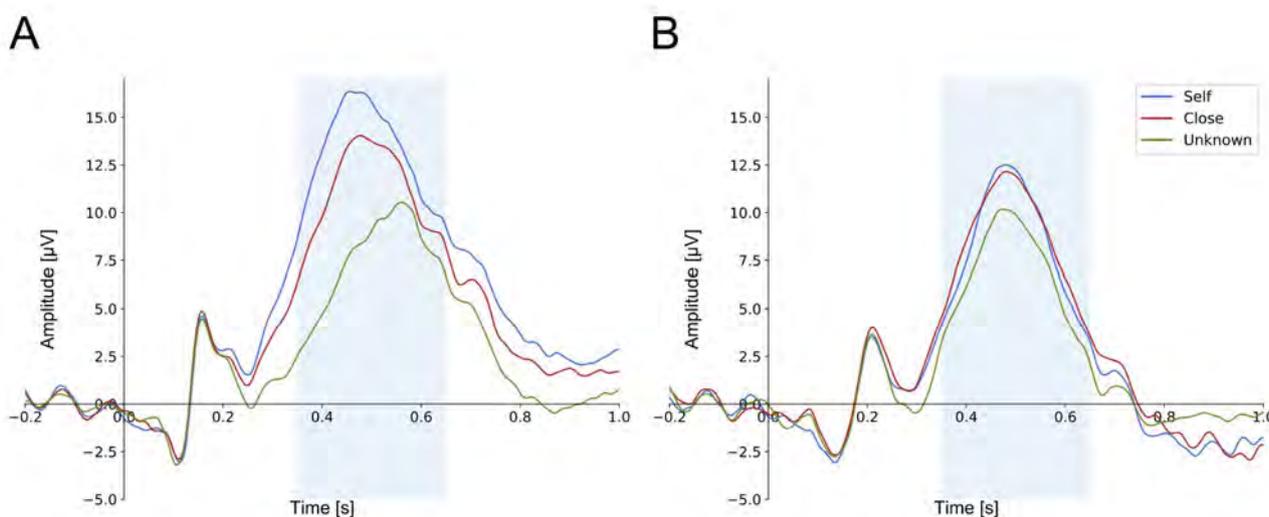


Fig. 5. Grand-average ERPs for (A) faces and (B) shapes, pooled for four electrodes: CP1, CPz, CP2, and Pz. The analyzed time window is marked by light-blue rectangles.

factor indicated that the P300 amplitude for faces was significantly higher than for shapes (see Fig. 5).

Post-hoc analyses for the “condition” factor showed that the unknown stimuli evoked significantly lower P3 than stimuli associated with the self ($P < 0.001$) as well as for stimuli associated with the close-other ($P < 0.001$). The difference between stimuli associated with self and close-other was non-significant ($P = 0.221$).

Post hoc tests performed for the two-way “condition” \times “type of stimulus” interaction revealed that the self-face was associated with significantly higher P3 than the shape assigned to the self ($P < 0.001$, $BF_{10} = 247366.068$, extreme evidence for H1). This was also the case for the close-other condition: P3 to the close-other’s face was larger than P3 to the shape assigned to a close-other ($P < 0.001$, $BF_{10} = 84.268$, very strong evidence for H1). Such an effect was not observed for unknown stimuli, as the difference between unknown faces and unknown shapes was not significant ($P = 0.165$, $BF_{10} = 0.470$, anecdotal evidence for H0). Moreover, P3 amplitude was significantly increased for self-face in comparison to close-other’s face ($P = 0.008$, $BF_{10} = 13.409$, strong evidence for H1) as well as in comparison to unknown faces ($P < 0.001$, $BF_{10} = 4.871 \times 10^6$, extreme evidence for H1), and for close-other’s face compared to unknown faces ($P = 0.001$, $BF_{10} = 7478.356$, extreme evidence for H1). P3 amplitudes to the self-assigned shape and the close-other assigned shape did not differ ($P > 0.999$, $BF_{10} = 0.207$, moderate evidence for H0). However, unknown shapes were associated with lower P3 amplitude than the shape assigned to the self ($P = 0.009$, $BF_{10} = 12.049$, strong evidence for H1) and to the close-other ($P = 0.004$, $BF_{10} = 25.077$, strong evidence for H1).

Cluster-based permutation tests

Nonparametric cluster-based permutation analyses showed that the self-face processing differed

significantly from the processing of all other faces, i.e. close-other’s and unknown faces. Differences between the self- and unknown faces as well as between the close-other’s face and unknown faces were widely distributed in space and time, whereas a significant cluster was more focused for the self vs. the close-other comparison (see Fig. 6). It is worth noting that the time window of substantial differences between the tested conditions encompasses the time window in which the P3 component was analyzed (350–650 ms). Moreover, differences between conditions were present at electrodes within the central-parietal region for all comparisons, i.e. the region for which P3 amplitudes were analyzed.

In the case of abstract shapes, nonparametric cluster-based permutation analyses revealed significant differences between the self-assigned shape vs. unknown shapes and the close-other assigned shape vs. unknown shapes (see Fig. 7). Crucially, when compared to the shape assigned to the close-other, no difference was detected in the case of the self-assigned shape, at any electrode site and at any time point (see Fig. 7). Such a lack of the differences indicates that the data in those two experimental conditions (self, close-other) came from the same probability distribution (i.e. the data in these conditions cannot be distinguished).

Discussion

Converging lines of evidence indicate that self-relevance facilitates stimulus processing and different types of self-related information (e.g. name, face) are processed preferentially (for a review see Humphreys and Sui 2016). There is an ongoing debate on whether such a self-advantage can be attributed to the extreme familiarity of self-related information and whether the processing advantages for self-related information can be observed

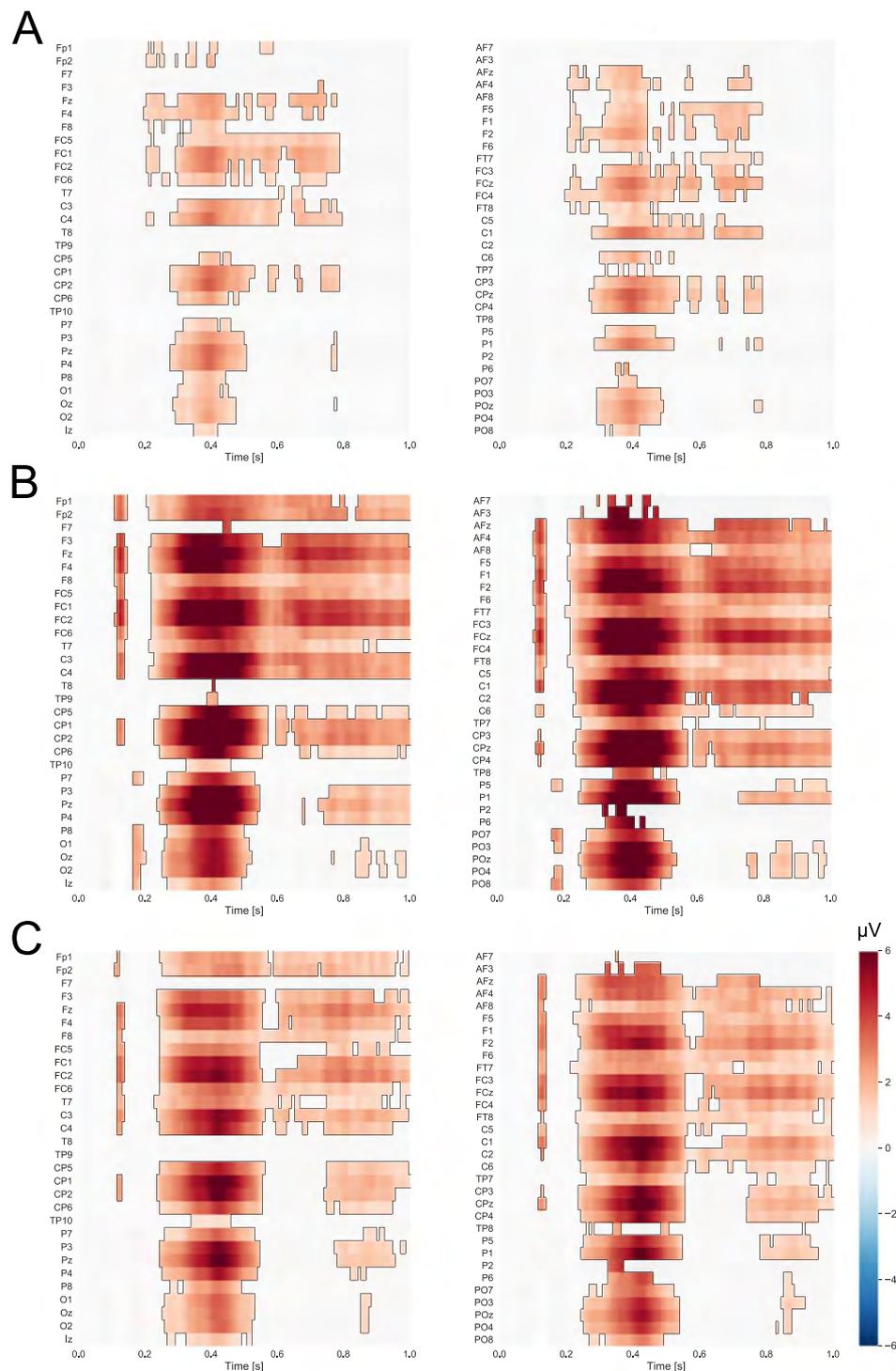


Fig. 6. The results of cluster-based permutation tests for faces. (A) Self-face compared to close-other and (B) unknown faces, (C) close-other face compared to unknown faces. Statistically significant positive differences between conditions are indicated in red ($P < 0.05$).

for initially unfamiliar information, when arbitrarily associated with the self (Sui et al. 2012).

The current study investigated the neural underpinnings and behavioral indices of the processing of self and close-other's faces as well as for abstract shapes that were—prior to the experimental session—assigned to the self and a close-other. It should be pointed out that the close-other condition seems to be the best control to the self and has been used in several previous studies on

self-referential processing (Cygan et al. 2014; Kotlewska and Nowicka 2015; Kotlewska and Nowicka 2016; Nowicka et al. 2016; Kotlewska et al. 2017; Nijhof et al. 2018; Nowicka et al. 2018; Cygan et al. 2021). The processing of those two types of faces and shapes was compared with the processing of unknown faces and shapes.

On the behavioral level, we observed a rather complex pattern of findings. To start with, accuracy rates were significantly higher for faces than for shapes in the “self”

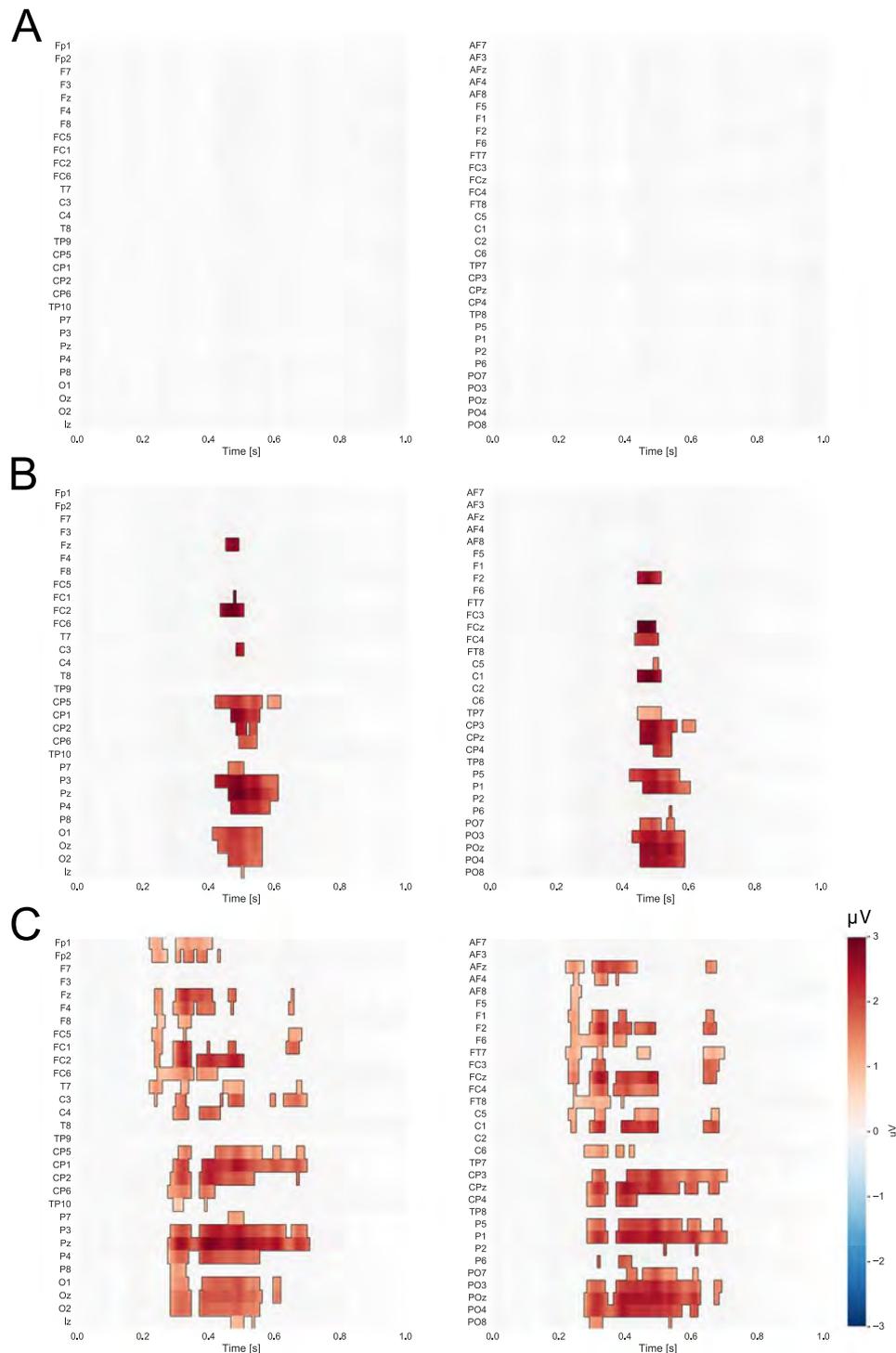


Fig. 7. The results of cluster-based permutation tests for shapes. The self-assigned shape compared to the shape assigned to (A) the close-other and (B) unknown shapes, and (C) the shape assigned to the close-other compared to unknown shapes. Statistically significant positive differences between conditions are indicated in red ($P < 0.05$).

and “close-other” conditions, but they were similar for faces and shapes in the “unknown” condition. Accuracy scores to the self-assigned shape and the shape assigned to the close-other did not differ. However, both were lower than accuracy score to unknown shapes. Even so, it should be pointed out that accuracy rates were nominally very high in each experimental condition (from 92 to 99%). RTs analyses revealed that all self-related

stimuli were characterized by shorter RTs in comparison to the other stimuli (i.e. referring to the close-other and unknown people). Additionally, it should be highlighted that this result was primarily driven by the RTs to faces—significant differences were observed between self-face and other faces, but not between shapes. Moreover, RTs to the self-face were significantly shorter than to the self-assigned shape. Such faster reactions to faces than to

shapes were not observed in the case of the “close-other” and “unknown” conditions.

Based on numerous studies showing behavioral indices of the self-prioritization effect for new information that is arbitrarily associated with the self (Sui et al. 2012; Sui et al. 2013; Frings and Wentura 2014; Sui et al. 2014; Mattan et al. 2015; Schäfer et al. 2015; Sui et al. 2015a; Schäfer et al. 2016; Macrae et al. 2017; Woźniak et al. 2018; Yin et al. 2019; Orellana-Corrales et al. 2021), one might also expect the current study to find shorter RTs and higher accuracy rates in the case of newly self-assigned stimuli. However, this was not the case. This discrepancy may be due to the substantial procedural/methodological differences between the previous studies and the current study.

To start with, one of the differences refers to the presence vs. absence of labels. Specifically, in the matching trials of the self-prioritization task used in previous studies, participants were processing not only self-associated arbitrary stimuli but also familiar verbal labels with a pre-experimentally established meaning. Therefore, the self-advantage may be caused by the familiarity of the labels, rather than the self-association of the shape. In contrast, the present study did not present labels with shapes. However, it should be noted that the self-prioritization effect in RTs was also observed in the absence of any pre-experimentally familiar stimuli related to the self (Woźniak and Knoblich 2019). Thus, the RT findings in the current study and in Woźniak and Knoblich (2019) may be regarded as inconsistent. However, the next difference between the current and previous studies on the topic of processing newly acquired information (including Woźniak and Knoblich 2019) is that in our study the control condition to the self was not just a “friend” but a person, freely chosen by each participant as the most significant person at the time of experimentation. Other differences are as follows. In the current study, shapes assigned to the self and the close-other were presented for a rather prolonged time (ca. 30 min), whereas in previous studies the process of associating a specific shape to a specific person was much shorter: each participant was simply told that they would be represented by e.g. a circle or a square (Sui et al. 2012) or the learning phase of shapes labels was very short—30 or 60 s (Woźniak and Knoblich 2019).

Crucially, the behavioral tasks performed by participants were different. While in previous studies, it was the perceptual matching task, in the current study it was the discrimination of familiar vs. unfamiliar stimuli. Thus a question may arise whether participants ignored self- and close-other associations when responding to the shapes and simply re-conceptualized those shapes as simply representing the category “familiar.” Such strategy was fully efficient in successfully accomplishing the task and accuracy rates seemed to support this view as they did not differ for self- and close-other assigned shapes.

It is worth noting that the self-relevance facilitated stimulus processing only when task sets drew attention to previously formed shape-label associations (Caughey et al. 2021). Compared to shapes associated with a friend, those paired with the self were classified more rapidly when participants were required to report who the stimulus denoted (i.e. self or friend). However, self-relevance failed to facilitate performance when participants judged either what the shape was (i.e. triangle or square, diamond or circle) or where it was located on the screen (i.e. above or below fixation). This was also the case for arbitrary objects assigned to the self and a friend (Falben et al. 2019). Compared with arbitrary objects owned by a friend, those owned by the self were classified more rapidly when participants were required to report either the owner or identity of the items. In contrast, self-relevance failed to facilitate performance when participants judged the orientation of the stimuli. In a similar vein, the self-prioritization effect was observed (in the absence of any stimuli with established self-associations) only when self-associations were task-relevant (Woźniak and Knoblich 2021). In the light of the aforementioned findings, behavioral results for shapes assigned to the self and a close-other were similar because the self-association of a shape was task-irrelevant as it was not necessary to identify shapes as associated with the self or a close-other.

Even so, we found faster reactions to one’s own face than to other faces. Our RTs results are in line with the findings reported in numerous studies, typically reporting shorter RTs to the self vs. other faces (Keyes et al. 2010; Ma and Han 2010; Tacikowski and Nowicka 2010; Żochowska et al. 2021). In a recent meta-analysis, RTs to the self-face were compared with RTs to other faces across a large number of studies (Bortolon and Raffard 2018). The tested moderators included—among others—the familiarity (i.e. whether the face was familiar to the participants) and identity of faces (i.e. whether the face belonged to someone personally known by participants, or whether it was a famous person or a stranger). The results of that meta-analysis showed that regardless of the face identity or level of familiarity, people tended to respond faster to their own face than to other people’s faces when requested to perform an identification/recognition task (Bortolon and Raffard 2018).

On the neural level, the ERP findings differed for faces and shapes. First of all, amplitudes of P3 to faces were—in general—higher than amplitudes of P3 to shapes. As the P3 component is linked to the cognitive evaluation of stimulus significance (Picton and Hillyard 1988), this finding may suggest the increased significance of faces in comparison with abstract shapes. While the former are ecologically valid stimuli that are encountered on an everyday basis, the latter definitely do not share those features. In addition, the ERP results of the present study clearly showed that self-face processing was associated with enhanced P3 in comparison with all other faces

(close-other's, unknown). Furthermore, P3 to the close-other's face was larger than P3 to unknown faces. Non-parametric cluster-based permutation tests corroborated our P3 findings, as they revealed significant clusters for the self-face when compared to both the close-other's face and unknown faces, as well as for the close-other's face when compared to unknown faces.

However, the pattern of findings was different in the case of shapes. P3 to the self-assigned shape and P3 to the close-other assigned shape were similar, and both were larger than P3 to unknown shapes. Moreover, non-parametric cluster-based permutation tests showed significant clusters for comparisons of "self vs. 'unknown'" and "close-other" vs. "unknown" conditions, but no significant cluster was detected for the self-assigned shape when compared to the close-other assigned shape. The latter is in line with the lack of differences in P3 amplitude between the self- and close-other conditions.

Due to methodological differences, it is rather difficult to directly compare our P3 findings for the self-assigned shape to previous ERP findings on the processing of newly acquired self-related information (Woźniak et al. 2018). In Woźniak et al.'s study with the matching task of labels and previously unknown faces, associated with the self and others, self-association of the first stimulus in a pair determined the pattern of P3 results for the second stimulus. In other words, the amplitude of the central-parietal P3 did not depend on the self-association of the stimulus that elicited the P3, but instead on the self-association of the preceding stimulus, regardless of whether this preceding stimulus was a label or a previously unknown face associated with one's own person.

However, our P3 results to faces corroborate the findings of previous studies reporting enhanced P3 to the self-face in comparison with other (either familiar or unfamiliar) faces (Sui et al. 2006; Keyes et al. 2010; Tacikowski and Nowicka 2010; Cygan et al. 2021; Żochowska et al. 2021). Such an effect was also repeatedly found for one's own face when compared to a close-other's face, if—similarly to the present study—the close-other was freely selected by participants as their most significant person (Cygan et al. 2014; Kotlewska and Nowicka 2015; Cygan et al. 2021).

In the present study, one of the main differences between the processing of faces and shapes referred to the relation between the "self" and "close-other" conditions. While those two conditions differed in the case of faces, they did not differ in the case of shapes, as indicated by significant differences found both in the neural underpinnings and in RTs for faces and lack of such differences for shapes. The most obvious explanation of this dissociation refers to the familiarity of processed information. Specifically, the self-advantage found for the self-face vs. close-other's face comparison was not observed if levels of familiarity of information referring to the self and the close-other were strictly equalized, as it was done for shapes. Thus, our P3 findings for the "self" and "close-other" conditions may be driven

by the higher pre-experimental familiarity of one's own face than the close-other's face.

Moreover, this pattern of P3 findings may also be interpreted in reference to the attentional processing of information related to the self and close-other. Specifically, it has been proposed that the mechanisms boosting the prioritized processing of self-relevant information could be driven by automatic capture of attention and prioritized allocation of attention to self-related stimuli (review Humphreys and Sui 2016; Sui and Rotshtein 2019). Indeed, several studies have found that the self-face automatically captures attention (Tong and Nakayama 1999; Brédart et al. 2006; Alexopoulos et al. 2012; Wójcik et al. 2018; Wójcik et al. 2019; Alzueta et al. 2020), and numerous EEG studies have revealed greater P3 amplitude in response to one's own face (Ninomiya et al. 1998; Sui et al. 2006; Tacikowski and Nowicka 2010; Kotlewska and Nowicka 2015; Żochowska et al. 2021; review: Knyazev 2013). The P3 is often associated with attentional processes (Polich 2007 but see Nieuwenhuis et al. 2005; Verleger et al. 2015), thus substantially enhanced P3 to the self-face, as reported in the current study, seems to reflect preferential engagement of attentional resources to one's own face. In the case of shapes, similar P3 amplitudes for the "self" and "close-other" conditions may be linked to comparable attention allocation, i.e. the self-assigned shape did not benefit from such preferential allocation of attentional resources.

In general, interpretations of P3 findings referring to attentional processes are in line with the notion that P3 reflects stimulus processing only, i.e. with the view that P3 is a signature of a comprehensive evaluation of incoming stimuli (McCarthy and Donchin 1981; Duncan et al. 2009). This evaluation entails processes of allocation of perceptual and attentional resources to event encoding and categorization (Duncan-Johnson 1981; Donchin and Coles 1988), and P3 amplitude is assumed to reflect the amount of these resources or cognitive capacity involved in the stimulus evaluation (Isreal et al. 1980; Kok 2001). However, the current debate on the functional role of the P3 component is multifaceted and it refers to many different topics. Thus, other interpretations of P3 findings are also plausible. To start with, an alternative view is that P3 reflects some processes of stimulus–response (S-R) translation or integration, a bridging step between sensory encoding and response execution (Pritchard et al. 1999; Verleger et al. 2005). Following this general idea, it was proposed that P3 reflects (re)activation of well-established S-R links as in typical laboratory tasks, usually a few fixed S-R links or S-R schemas are established by instruction and practice (Verleger et al. 2014; Verleger et al. 2015). Such a link binds a stimulus-code with its corresponding response-code, leading to the automatic activation of the corresponding, already well-established, motor program, matching the presented visual stimulus (Hommel 2004), and this process is assumed to be reflected by P3 (Verleger et al. 2015). However, the design

of our study was not intended to test the impact of S-R links on P3. Moreover, different patterns of P3 findings observed for familiar vs. unfamiliar shapes and faces did not provide any support for the S-R hypothesis.

Moreover, one may view P3 findings reported in the current study in the light of the locus coeruleus-noradrenergic (LC-NE) system activity. The pivotal role of the LC-NE system in regulating task engagement is well documented (Aston-Jones and Cohen 2005). Through its modulatory actions on information processing, the LC-NE system potentiates responses to the outcome of internal decision processes that involve motivationally significant events, thereby guiding behavioral action in the service of task demands and other goals (Aston-Jones and Cohen 2005). The modulatory effects of the LC-NE system may be measurable at the scalp as the P3 component. Thus, P3 is considered to be one of the psychophysiological markers of LC-NE activity (Murphy et al. 2011). Specifically, according to the LC-P3 hypothesis, the phasic activity of the LC and the resulting release of NE at axon terminals is critical in generating the P3 (Aston-Jones and Cohen 2005). It was also proposed that the P3 reflects the response of the LC-NE system to the outcome of internal decision-making processes and the consequent effects of noradrenergic potentiation of information processing (Nieuwenhuis et al. 2005).

So far, we viewed our P3 findings in the light of attentional mechanisms. However, this view may be complemented by the interpretation of P3 as reflecting processing of stimuli that are highly arousing in nature (Hu et al. 2011). These two interpretations—seeing the P3 amplitude as an index of attention or as an index of emotional arousal—are not mutually exclusive. According to Lang et al.'s (1997) model of motivated attention, emotional cues prompt motivational regulation and draw attentional resources. In fact, many behavioral (Armony and Dolan 2002) and electrophysiological (Cuthbert et al. 2000; Keil et al. 2002; Schupp et al. 2004; Briggs and Martin 2009; Foti et al. 2009; Hajcak et al. 2010; Franken et al. 2011) studies support this relationship between emotions and attention. Recent definitions of emotions emphasize their subjective character, i.e. emotions could be conceptualized as complex constellations of psychological and physiological states that reflect an organism's appraisal of the meaning, relevance, and value of incoming stimuli (Dolan 2002). In this context, it is the motivational relevance of a particular stimulus to a particular person that determines the emotional vs. neutral evaluation. Our results for faces are in line with this interpretation: P3 findings may be attributed to the different emotional/motivational content of the self-face and other (close, unknown) faces, with the self-face being the most motivationally relevant.

As the P3 component reflects the cognitive evaluation of stimulus significance (Picton and Hillyard 1988; Mangun and Hillyard 1995; Bernat et al. 2001; Carretié et al. 2001), different patterns of P3 findings for faces

and shapes (i.e. differences between the self-face and close-other's face and the lack of differences between the self-assigned shape and the shape assigned to the close-other) may be due to the fact that new information associated with the self and the close-other evokes similar emotional responses and is characterized by similar levels of saliency, whereas the self-face is a more salient stimulus than the close-other's face. Saliency of the self-face is often viewed as the primary driving factor of prioritized processing of that stimulus, and self-faces are among the most salient stimuli that we come across and process frequently (Devue and Brédart 2008; Apps et al. 2015; Wójcik et al. 2018; Wójcik et al. 2019). Self-relevant stimuli engage emotional processes and seeing one's own face evokes a rather unique emotional response (Kircher et al. 2000). Such self-face advantage was observed even when the processing of one's own face was directly compared to the processing of emotional (both happy and fearful) faces (Żochowska et al. 2021). Although in the current study the close-other's face was chosen as an emotionally salient and overlearned non-self-face, the P3 and permutations tests differentiated these two faces. However, it was not the case for the self- and close-other assigned shape.

The limitations of the current study are as follows. Shapes were arbitrarily assigned to one's own person and to the chosen close-other, and their processing was compared to unknown shapes. As those familiar conditions (the self and the close-other) are personally relevant, it is a matter of debate whether similar—or rather dissimilar—patterns of behavioral and electrophysiological findings would be observed for shapes assigned to famous people. Therefore, the inclusion of such an additional experimental condition would provide a more global view on the processing of newly acquired information referring to the self and others. Moreover, our study did not provide an answer to the question of whether the self-relevance of newly acquired information triggers the self-representation in the brain, similarly to highly familiar self-referential information (self-face). In order to adequately relate to this issue, some source analyses (i.e. dipole fitting, LORETA, CLARA) should be done. However, due to rather a low number of experimental trials, such analyses—in the case of our present study—would be not very reliable. Future EEG studies may investigate whether newly learned and long-term established self-related information are represented in the same (or overlapping) neural network in the brain.

In conclusion, P3 and permutation test results revealed a clear self-advantage in the case of faces, i.e. significant differences between the processing of the self-face and other faces (close-other's, unknown). These findings may be viewed in the light of preferential attention allocation to highly familiar and well-established self-referential information. However, the processing of new information arbitrarily assigned to one's own person and the close-other did not differ. We propose that this effect is

mainly driven by similar attentional biases to self- and close-other assigned shapes.

Authors contributions

AŻ and AN conceived and designed the study. AŻ and PJ collected the data. AŻ, PJ, and MN analyzed the behavioral and EEG data. AŻ and MN prepared all the figures. AŻ and AN wrote the manuscript. All authors read and approved the final manuscript.

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